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Issue 127

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In the summer of 1958, the most famous space agency was founded: the National Aeronautics and Space Administration, or NASA. From leading the landing of humans on the surface of the Moon and the construction of the Skylab space station to sending a fleet of orbiters, landers and rovers to other worlds in the Solar System and launching a team of missions to understand the laws that govern the existence of the universe, the agency has been at the forefront of our biggest strides into space. I can guarantee that you'll learn something you didn't know about NASA, which graces the cover as our major feature this issue.

You can find the efforts of the space agency throughout your copy of *All About Space*, as you can with all issues of our magazine. This month we also explore the Large Magellanic Cloud satellite galaxy, reveal how you can get the very best views and images of the International Space Station from your garden or a dark-sky site and where we're at in our search for exomoons – you may have seen a mention of these natural satellites beyond our Solar System in the news recently.

Enjoy the issue and see you next time! Don't forget to download your free digital editions of *Book of Mars* and *Everything You Need to Know About Mars*.

GEMMA LAVENDER
CONTENT DIRECTOR

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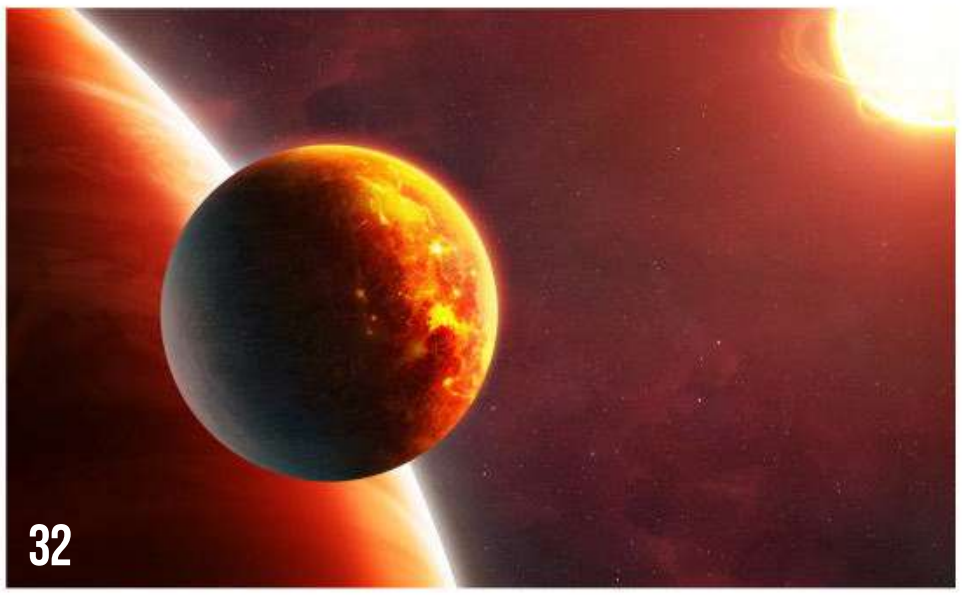

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24 JANUARY 2022

Galactic butterfly effect

Approximately 60 million light years away, the galaxies NGC 4567 and NGC 4568 are colliding and merging. Aptly nicknamed the Butterfly Galaxies, this cosmic collision, located in the constellation Virgo, gives us an insight into the eventual fate of the Milky Way. Scientists believe that our home galaxy will undergo a similar encounter with our neighbouring galaxy Andromeda. This image was captured by the FOcal Reducer and low dispersion Spectrograph 2 (FORS 2) instrument mounted on the European Southern Observatory's Very Large Telescope (VLT) at the Paranal Observatory in the Chilean Andes.

© ESO

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

28 JANUARY 2022

Martian tree stump

A Mars probe has snapped a peculiar feature on the Red Planet's surface that looks like a giant tree stump – rings and all. The ExoMars Trace Gas Orbiter (TGO), a joint mission by the European Space Agency (ESA) and Russia's space agency Roscosmos, studies Mars from above, circling the planet and collecting data about its sparse atmosphere. But this orbital vantage point also allows the TGO to see Mars from above, snapping images with its Color and Stereo Surface Imaging System (CaSSIS) instrument. The interior of this crater is filled with ice deposits that settle in this formation depending on how the planet's tilt, or spin axis, has changed over time.

© ESA

19 JANUARY 2022

Prichal spacewalk

Cosmonauts Pyotr Dubrov and Anton Shkaplerov are pictured here busy at work configuring and activating Russia's newest module with the Russian segment of the International Space Station. Dubrov can be seen in the lower-left portion of the image and Shkaplerov can be spotted working on the top right of the module. This spacewalk lasted seven hours and 11 minutes. Prichal is Russian for 'pier' and features six new ports for the stations' Russian segment, five of which are available for arriving ships.

© NASA

HOW NASA'S JAMES WEBB SPACE TELESCOPE WILL GET READY FOR ITS FIRST COSMIC OBSERVATIONS

Words by Elizabeth Howell

With NASA's newest space observatory exactly on schedule in its commissioning phase, the science team outlined their plan to make the most of this opportunity. The James Webb Space Telescope arrived on 24 January at its destination at Earth-Sun Lagrange Point 2 (L2), which is about 1.5 million kilometres (930,000 miles) from our planet. The principal investigators of the Webb science team outlined their plan in a town hall on 28 January hosted online by the Space Telescope Science Institute (STScI) in Baltimore.

Jonathan Gardner, Webb deputy senior project scientist at NASA Goddard Space Flight Center, walked through the last few months of preparations before giving a brief update on how things are going in orbit. "In a few words, everything is going to plan", he noted. "There were 50 major deployments; they have all been successful," he said of the telescope's mirror unfolding, as an example of the major milestones Webb achieved.

Meanwhile, amateurs and professionals alike are already sending back data from backyard observatories and professional locations. For example, he said, people have also been taking 'light curves' at places such as the National Science Foundation's Green Bank Telescope. Webb's brightness changes in a repeatable six-hour cycle as the observatory's solar array reflects a glint of sunlight back towards Earth during its regular spin, Gardner said. "The sunshield reflects the sunlight directly at Earth, and [sometimes] has a glint, and at other times it's more diffuse light," Gardner said.

Commissioning is still going to take several more months, said Mike McElwain, Webb observatory project scientist at Goddard. "We'll be aligning the telescope; that's about a three-month process that we're planning to begin early next week," he said, noting that optical performance of the telescope will be assessed to, among other things, determine the amount of stray light being produced by the optics. Optical commissioning will include several complex steps – sometimes sequentially and sometimes iteratively – such as identification of images, aligning different mirror segments and eventually phasing the segments to within a fraction of a wavelength, McElwain noted.

To guide mirror alignment, the Webb team will focus each of the 18 primary mirror segments on a bright, distant star called HD 84406, which is part of the constellation Ursa Major. An additional layer of complexity during commissioning is that the telescope's performance will change as it continues to cool. Eventually Webb's operating temperature will be about 45 Kelvin, a few degrees above absolute zero, which is equal to -228 degrees Celsius (-379 degrees Fahrenheit), but commissioning is ongoing as the telescope changes temperature.

Webb will always have a slight 'jitter', though, due to expected reaction wheel and cryocooler vibrations. The telescope will drift very slightly over time, too, due to solar heating on the observatory. While these disturbances to the telescope are expected to be very tiny, engineers will periodically make adjustments as required, McElwain said. The team is now getting ready to transition into science operations through commissioning the instruments, an activity that was set to begin as the instruments turned on.

Above: Webb's instruments are being switched on as the telescope continues its commissioning

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EUROPEAN SUN PROBE FLEW THROUGH THE TAIL OF COMET LEONARD

© ESA

Words by Meghan Bartels

As Comet Leonard bid farewell to Earth and flew past Venus, a Sun-studying spacecraft flew through the comet's long tail, giving humans a new perspective on the icy wanderer. Discovered last January and also known as Comet C/2021 A1, Comet Leonard was perhaps the most spectacular visitor for skywatchers in 2021.

The object put on quite a show as it zoomed towards the Sun, particularly in the days leading up to its closest approach to Earth on 12 December. And, coincidentally, the European Space Agency's (ESA) Solar Orbiter mission flew through the comet's tail as the spacecraft continued its own journey to study the Sun, offering scientists quite a bonus. "The big advantage is that for basically no effort on the spacecraft's part, you get to sample a comet at a massive distance," said Samuel Grant, a postgraduate student at University College London. "That's pretty exciting."

The spacecraft gathered cometary data for several days around 17 December. At the time, Comet Leonard was moving away from Earth towards the Sun, which it approached most closely on 3 January. The Solar Orbiter had completed an Earth flyby on 27 November and was also headed out to the Sun, which it will fly past in March. Although the nucleus of the comet was near Venus and about 44.5 million kilometres (27.7 million miles) away from the spacecraft in mid-December, the comet's tail stretched past Earth's orbit.

Above: A set of superimposed images captured by the Solar Orbiter show Comet Leonard and its two tails in visible light

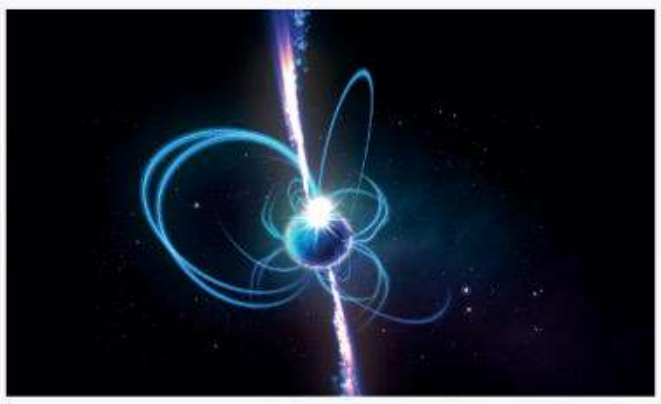
ASTRONOMERS DETECT A POWERFUL COSMIC OBJECT UNLIKE ANYTHING THEY'VE SEEN BEFORE

Words by Brandon Specktor

Astronomers have discovered a mysterious, flickering object in our galaxy that belches enormous amounts of energy towards Earth three times an hour. This strangely powerful object – located about 4,000 light years from the Sun – is unlike any cosmic structure ever observed. The object in question, called GLEAM-X J162759.5-523504.3, appeared out of nowhere on a recent radio wave survey of the Milky Way. According to researchers, GLEAM-X brightened rapidly over the course of about 60 seconds, briefly becoming one of the brightest objects in the entire sky, then suddenly faded into darkness again. About 20 minutes later the object reappeared, before dimming back to nothing a minute later.

Objects like these, which appear and disappear before our lenses, are known as transients. Typically, transients represent either a dying star, a supernova, or the bizarre, rapidly spinning corpse of an already-dead star, also known as a neutron star. However, neither of those standard explanations quite fit with the behaviour of this newfound object. It's possible that the mysterious GLEAM-X is evidence of a new type of stellar object that has only been theorised until now – or even one that astronomers haven't even dreamt up.

"This object was appearing and disappearing over a few hours during our observations. That was completely unexpected," said Natasha Hurley-Walker, a radio astronomer at Curtin University in Bentley, Australia. "It was kind of spooky for an astronomer because there's nothing known in the sky that does that." Now that GLEAM-X has been detected, the researchers are also digging into archival observations to see if any similar objects have ever turned up.



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Left: It blinks too fast to be a supernova and too slow to be a pulsar. What in the cosmos is it?

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BIZARRE ALIEN PLANET HAS A LAYERED ATMOSPHERE OF VAPORISED METALS

Words by Meghan Bartels

© ESA

Scientists have spotted the first evidence of an alien world with an atmosphere that's layered like Earth's – although perhaps a little too toasty for human tastes. The planet, dubbed WASP-189 b, isn't a new discovery. Scientists already knew that the world, which lies about 322 light years from Earth, is a gas giant that orbits its star 20 times closer than Earth does the Sun, making it a sweltering world.

"In the past, astronomers often assumed that the atmospheres of exoplanets exist as a uniform layer," said Jens Hoeijmakers, an astrophysicist at Lund Observatory in Sweden. "But our results demonstrate that even the atmospheres of intensely irradiated giant gas planets have complex three-dimensional structures."

Scientists used observations gathered in 2019 by the High Accuracy Radial velocity Planet Searcher (HARPS) instrument at La Silla Observatory in Chile during three different passes of the planet in front of its star. Among the specific chemicals the team identified was one of particular interest, titanium oxide, which they think could be absorbing short-wavelength light, as Earth's ozone layer does. Also in the atmosphere are a handful of different metals, including iron, chromium, magnesium and vanadium. While humans don't usually think of metals as being gaseous, given the temperatures at WASP-189 b, it's not surprising. The planet's star is particularly hot, and the planet is so close it takes just 2.7 Earth days to orbit around it.

Above: An artist's depiction of the planet WASP-189 b orbiting its hot, blue star

WATER ON MARS MAY HAVE FLOWED FOR A BILLION YEARS LONGER THAN THOUGHT

Words by Elizabeth Howell

Observations by a long-running Mars mission suggest that liquid water may have flowed on the Red Planet as little as 2 billion years ago. Scientists charted the presence of chloride salt deposits left behind by flowing water using years of data from NASA's Mars Reconnaissance Orbiter (MRO), which has been orbiting the Red Planet since 2006. By studying dozens of images of salt deposits taken by the craft's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), the scientists interpreted a younger age for the salt deposits using the method of crater counting. The younger a region is, the fewer craters it should have, with adjustments for aspects such as a planet's atmosphere, allowing scientists to estimate its age.

The new results push forward the existence of water on Mars from 3 billion years ago to as little as 2 billion years ago based on the observations, which could have implications for life on Mars and, more broadly, the planet's geological history.

"Part of the value of the MRO is that our view of the planet keeps getting more detailed over time," said Leslie Tamppari, the MRO's deputy project scientist at NASA's Jet Propulsion Laboratory. "The more of the planet we map with our instruments, the better we can understand its history." The salt minerals were first spotted by a different spacecraft 14 years ago, called Mars Odyssey, but the MRO's advantage is it has higher resolution instruments than its older companion in orbit.

© NASA/JPL-Caltech

Left: This image from NASA's MRO shows the Bosporos Planum plain on the Red Planet. The white specks are salt deposits found within a dry channel – a clue to its watery past

IN COOPERATION WITH SPACE.com

AN ANCIENT SOLAR STORM SMASHED EARTH AT THE WRONG PART OF THE SUN'S CYCLE, AND SCIENTISTS ARE CONCERNED

Words by Brandon Specktor

A very powerful solar storm pummelled our planet 9,200 years ago, leaving scars on the ice buried deep below Greenland and Antarctica. A new study of those ancient ice samples has found that this storm is one of the strongest outbursts of solar weather ever detected.

Surprisingly, the storm appears to have hit during a solar minimum, the point during the Sun's 11-year cycle when solar outbursts are typically much less common. Because of this unexpected discovery, the researchers are concerned that devastating solar storms could hit when we least expect them, and that Earth might not be prepared when the next big one arrives. "These enormous storms are currently not sufficiently included in risk assessments," said Raimund Muscheler, a geology researcher at Lund University in Sweden. "It's of the utmost importance to analyse what these events could mean for today's technology and how we can protect ourselves."

© NASA

Right: The 9,200-year-old storm left researchers with a stark conclusion: we are not ready for the next one

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NASA

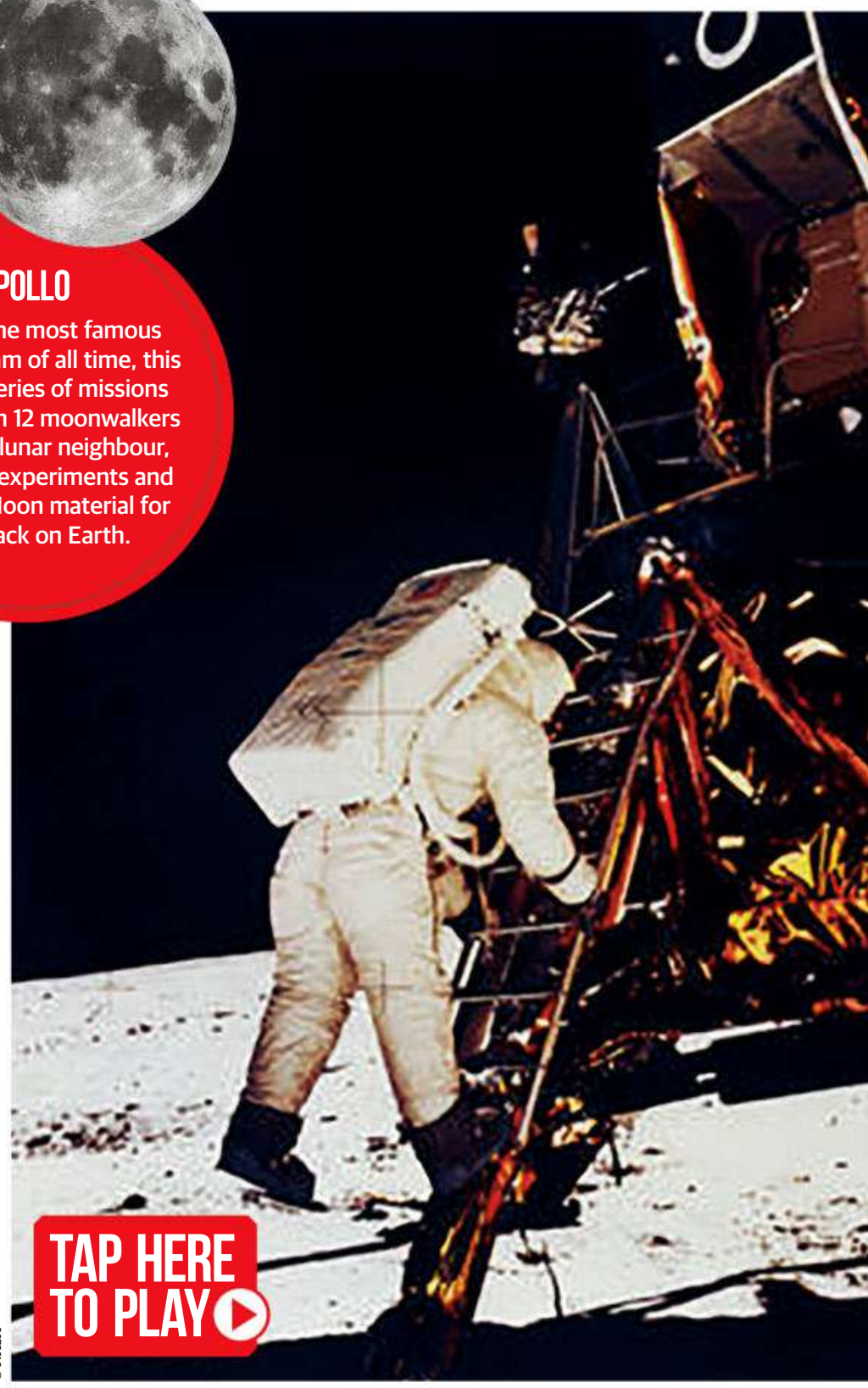
COMPLETE GUIDE TO NASA

IT'S AN ORGANISATION KNOWN THE WORLD OVER, WITH ITS AMBITIOUS GOALS INSPIRING OTHERS TO DREAM OF TRAVELLING AMONG THE STARS. HERE'S YOUR DEFINITIVE GUIDE TO THE HISTORY OF NASA

Written by Colin Stuart

APOLLO

Probably the most famous NASA program of all time, this ambitious series of missions culminated in 12 moonwalkers visiting our lunar neighbour, performing experiments and collecting Moon material for study back on Earth.



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1950s

The National Aeronautics and Space Administration was founded on 29 July 1958 when President Eisenhower signed the National Aeronautics and Space Act. It was a direct response to the launch of the world's first satellite, Sputnik 1, by the Soviet Union on 4 October 1957. "It is of great urgency and importance to our country, both from consideration of our prestige as a nation as well as military necessity, that this challenge be met by an energetic program of research and development for the conquest of space," read a report from January 1958. NASA was established to do just that.

Attention quickly turned to human spaceflight with the commencement of Project Mercury. Seven potential astronauts, known as the 'Mercury Seven', were selected from a pool of US test pilots. Candidates had to be between 25 and 40 years old, and no taller than 5 feet 11 inches (1.8 metres). Their identities were announced to the world on 9 April 1959. A group of female candidates, now known as the 'Mercury 13', were not included.

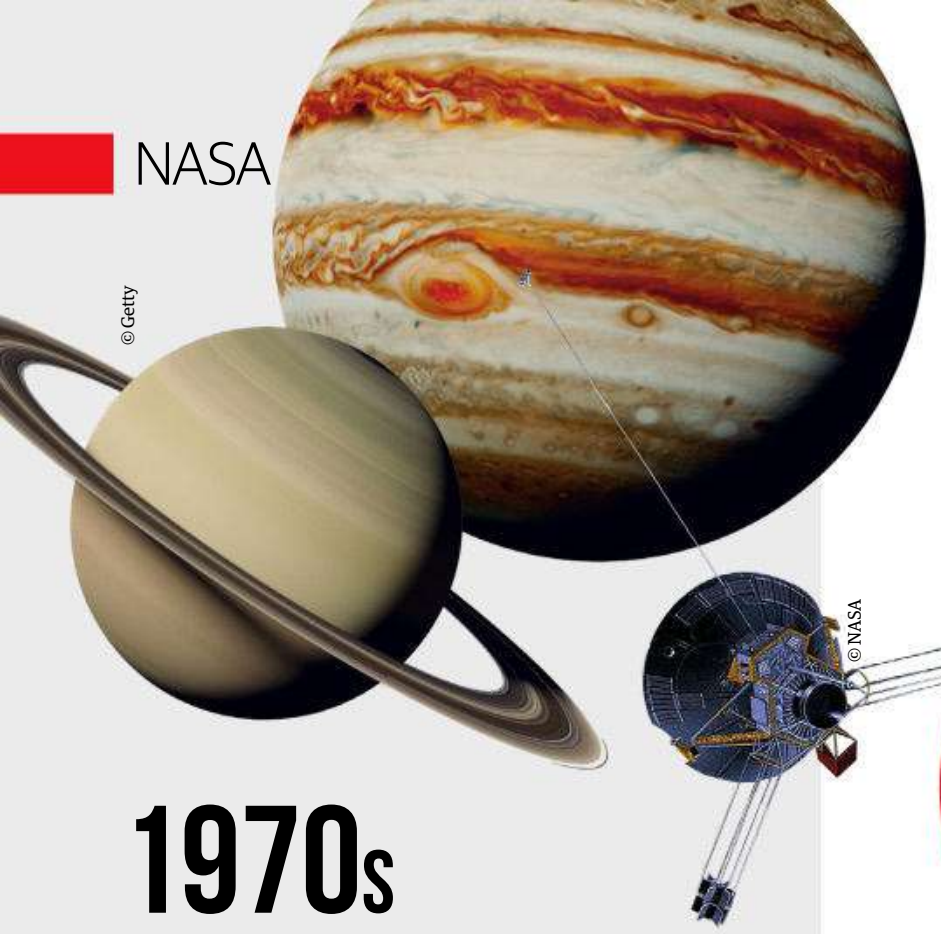
© NASA

1960s

NASA was pipped to the post again when Soviet cosmonaut Yuri Gagarin became the first human in space on 12 April 1961, completing one orbit of the planet. On 5 May the same year, Alan Shepard became the first American in space when he undertook a 15-minute suborbital flight aboard the Freedom 7 spacecraft. Three weeks later, President John F. Kennedy took things up a gear by setting the ambitious goal of landing astronauts on the Moon by the end of the decade.

After testing spaceflight capabilities with the Gemini program, NASA started its fabled Apollo program to meet Kennedy's target. After much planning, Apollo 8 and Apollo 10 saw astronauts fly around the Moon for the first time. Then, on 20 July 1969, Neil Armstrong and Buzz Aldrin set foot on the lunar surface. An estimated 650 million viewers watched worldwide – about one out of every six people on the planet. At last NASA had a significant Space Race victory over the Soviet Union. Two more moonwalkers, Pete Conrad and Alan Bean, left their footprints in the lunar dust before the decade was out as part of the Apollo 12 mission.

© NASA; Getty



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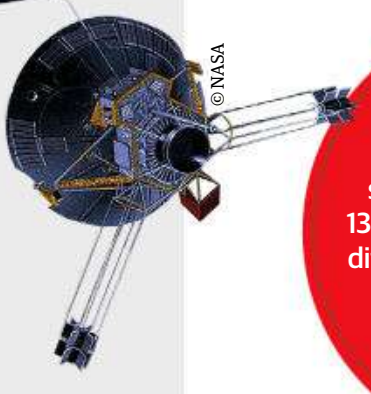

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1970s

There were four more successful Moon landings in the 1970s, but the decade was just as notable for advances in robotic space exploration. It was the decade of getting to know our neighbouring planets. In 1973 the NASA spacecraft Pioneer 11 flew by both Jupiter and Saturn, while the same year saw Mariner 10 whizz past Mercury and Venus. The twin Viking 1 and Viking 2 landers touched down on the surface of Mars in 1976, sending back NASA's first in-situ pictures of the Martian terrain. Experiments on board initially detected signs of life, but this was later established as a false positive.

In 1977, Voyager 1 and Voyager 2 were lofted into the Solar System to explore the realm of the gas planets beyond the asteroid belt. They both arrived at Jupiter before the decade was out, sending back over 52,000 images of the Solar System's largest planet. The biggest surprise was that Jupiter's moon Io is volcanically active and spewing plumes of material hundreds of metres into space.

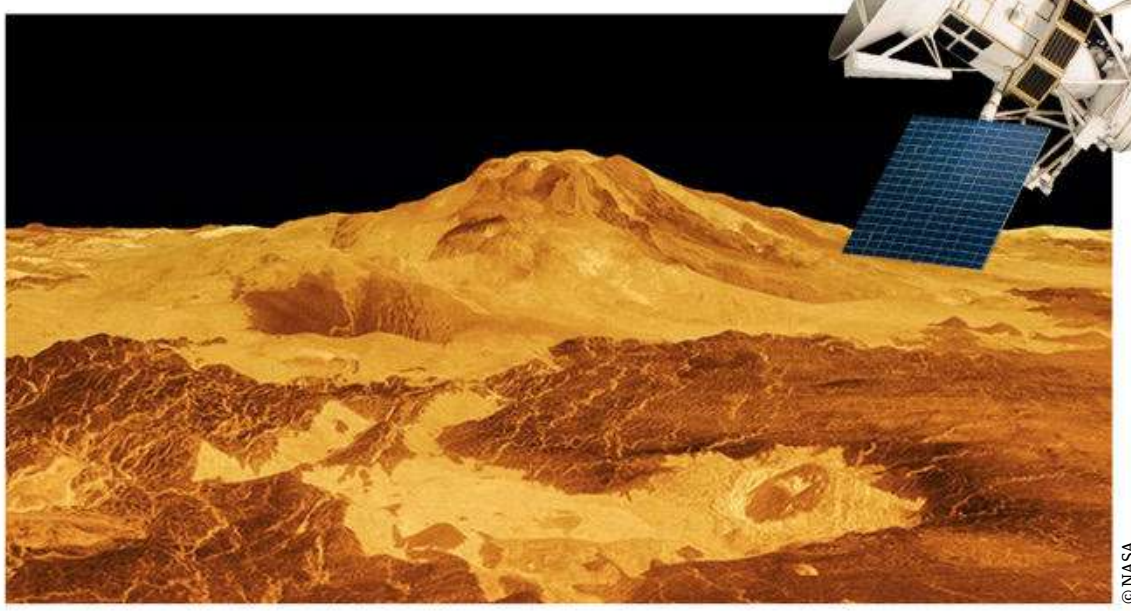
"IT WAS THE DECADE OF GETTING TO KNOW OUR NEIGHBOURING PLANETS"

VOYAGER

Now the farthest human-made objects from Earth, the Voyager craft gave us the first close-up look at the gas giants.

© NASA/JPL

Right: We have very few images from Venus' hostile surface as spacecraft don't survive there long



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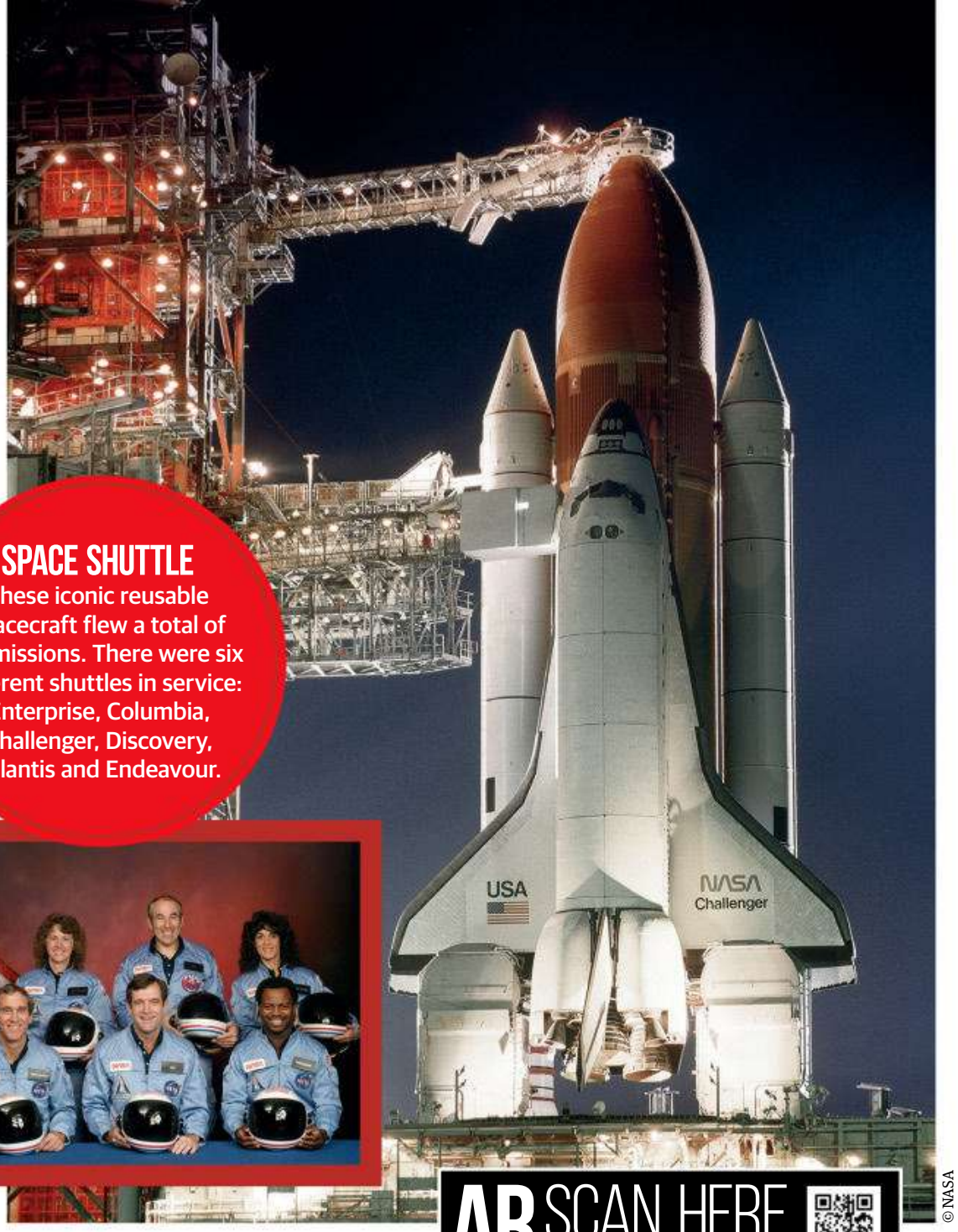

SPACE SHUTTLE

These iconic reusable spacecraft flew a total of 135 missions. There were six different shuttles in service: Enterprise, Columbia, Challenger, Discovery, Atlantis and Endeavour.

© NASA

© NASA

1980s

This was the first decade of NASA's iconic Space Shuttle. Four fully operational orbiters were initially built. Columbia was the first into space on 12 April 1981 – the 20th anniversary of Gagarin's maiden spaceflight. One of the shuttles' key attributes was their reusability. After launching attached to a distinctive orange fuel tank, the shuttles glided back to Earth after each mission to be used again in the future. But disaster struck in 1986, when Challenger exploded 73 seconds after launch. All seven crew members were lost. The accident grounded the shuttle fleet for more than two-and-a-half years, and the Endeavour shuttle was built to replace Challenger. An investigation concluded that a faulty seal allowed pressurised gas to burn through one of the external fuel tanks. While all this was going on, Voyager 2 reached Saturn in 1981, Uranus in 1986 and Neptune in 1989. It remains the only probe to have visited the two outer planets. The final year of the decade also saw NASA's Magellan probe orbit Venus and the Galileo spacecraft visit Jupiter.

1990s

In April 1990, NASA finally launched the Hubble Space Telescope after a myriad of delays brought on by the Challenger disaster. It was supposed to revolutionise our ability to look deep into space, but mission scientists quickly realised there was a defect with the telescope's mirror – it had been misaligned by an amount equivalent to just 1/50th the width of a human hair.

It took until 1993 to correct the error, when astronauts flew up on the Space Shuttle Endeavour to retrofit a solution called the Corrective Optics Space Telescope Axial Replacement (COSTAR). About the size of a telephone booth, it's the equivalent of a pair of glasses to restore the telescope's ailing vision.

Ulysses, a spacecraft sent to study the Sun's more extreme latitudes, launched on the Space Shuttle Discovery six months after Hubble. Later in the decade, on 4 July 1997, NASA landed Pathfinder on Mars. It was carrying Sojourner, the first-ever Mars rover. Slow Sojourner took three months to trundle just 100 metres (328 feet) through the Martian dust, analysing rocks as it went.

HUBBLE

Supplying scientists with 30 years of data – and wowing us with its images – Hubble has made many breakthroughs possible.

© NASA

AR SCAN HERE

NASA LOCATIONS

NASA has sites all across the US, though they carry out many different types of research

AMES RESEARCH CENTER

1 Located in the heart of California's Silicon Valley, Ames provides leadership in areas including astrobiology and robotic lunar exploration.

ARMSTRONG FLIGHT RESEARCH CENTER

2 Located inside Edwards Air Force Base in California, this is NASA's main location for aeronautical research.

JET PROPULSION LABORATORY

3 The JPL predates NASA and is famous for constructing robotic spacecraft, including all of NASA's Mars rovers.

WHITE SANDS TEST FACILITY

4 Set in the western foothills of the Organ Mountains of New Mexico, White Sands is where NASA tests its rocket engines and boosters.

JOHNSON SPACE CENTER

5 The Johnson Space Center in Houston, Texas, is NASA's centre for human spaceflight, including astronaut training and Mission Control.

MICHOUD ASSEMBLY FACILITY

6 One of the largest manufacturing plants in the world, parts of the famous Saturn V rocket were built here.

STENNIS SPACE CENTER

7 America's largest rocket engine test facility, it's located on the banks of the Pearl River on the Mississippi–Louisiana border.

KENNEDY SPACE CENTER

8 The launch site of the Apollo missions to the Moon, as well as the Space Shuttle. It was named after the president.

MARSHALL SPACE FLIGHT CENTER

9 The largest NASA centre, it's the US government's civilian rocketry and spacecraft propulsion research base.

MARY W. JACKSON NASA HQ

10 Named after one of the black female scientists depicted in the film *Hidden Figures*, it's the administration centre of NASA in the US capital.

LANGLEY RESEARCH CENTER

11 This base is home to more than 40 wind tunnels, which are used to study craft safety and efficiency.

WALLOPS FLIGHT FACILITY

12 Located on Wallops Island, the technology tested at Wallops includes sounding rockets and high-altitude balloons for astronomical research.

GODDARD SPACE FLIGHT CENTER

13 Spacecraft, instruments and new technology to study Earth, the Sun, our Solar System and the universe are built here.

NEIL A. ARMSTRONG TEST FACILITY

14 Home to several world-class test facilities which perform complex and innovative ground tests for the space community.

KATHERINE JOHNSON INDEPENDENT VERIFICATION AND VALIDATION FACILITY

15 Named after another 'hidden figure', the software for NASA's space missions is put through its paces here.

GLENN RESEARCH CENTER

16 This facility in Cleveland, Ohio, designs and develops innovative technology to advance NASA's missions in aeronautics and space exploration.

GODDARD INSTITUTE FOR SPACE STUDIES

17 Conducts theoretical and experimental research in astrophysics, planetary atmospheres and climate studies.

STANDOUT MOMENTS IN NASA HISTORY

29 JULY 1958

National Aeronautics and Space Administration was founded

President Eisenhower signed the National Aeronautics and Space Act in response to Sputnik.

5 MAY 1961

Alan Shepard became the first NASA astronaut

He spent 15 minutes in space on a suborbital flight.

20 JULY 1969

First crewed Moon landing

Neil Armstrong and Buzz Aldrin made history as the first moonwalkers.

12 APRIL 1981

First Space Shuttle launched

The first Space Shuttle to leave Earth was the ill-fated Columbia.

28 JANUARY 1986

Challenger exploded just after launch

The death of seven crew members saw the fleet grounded for more than two years.

2 NOVEMBER 2000

The first crew visited the International Space Station

It was the beginning of staying in space for months rather than days at a time.

1 FEBRUARY 2003

Columbia broke up on re-entry

A second catastrophic disaster befell the Space Shuttle, resulting in the loss of the entire crew.

31 AUGUST 2011

The formal end of the Space Shuttle program

The Space Shuttle was retired after Atlantis made the 135th and final flight in July 2011.

9 DECEMBER 2020

Artemis lunar mission crew announced

18 astronauts were selected for Artemis Team, from which the next moonwalkers will be picked.

"IT QUICKLY BECAME AN IDEAL ORBITAL OUTPOST ON WHICH WE COULD LEARN MORE ABOUT LONG-DURATION HUMAN SPACEFLIGHT"

INTERNATIONAL SPACE STATION

Assembled in segments over the course of over ten years and 30 missions, the ISS is a collaboration between NASA, the European Space Agency, Roscosmos, the Japan Aerospace Exploration Agency and the Canadian Space Agency.

TAP HERE TO PLAY

2000s

The newly constructed International Space Station (ISS) got its first crew. It quickly became an ideal orbital outpost on which we could learn more about long-duration human spaceflight. To this day, more NASA astronauts have flown to the ISS than any other nation's space travellers. A second disaster occurred when Columbia broke up on re-entry in 2003, killing all seven of the crew.

Planetary exploration was dominated by Saturn and Mars. NASA's Cassini probe arrived at the ringed planet in 2004 and began sending back jaw-dropping images of the planet, its rings and its moons. That same year the twin Spirit and Opportunity rovers landed on Mars, returning stunning pictures of Martian sunsets and Earth hanging in the Martian sky. Spirit eked out an existence until getting stuck in the mud in 2010. Remarkably, Opportunity lasted until 2019, despite the fact it was only designed to work for 90 days. NASA also got to know the Moon even better thanks to the Lunar Reconnaissance Orbiter (LRO), which launched in 2009. It returned images of the Apollo 11 landing site, including the Eagle lander glinting in the sunlight.

Below: All seven of Columbia's crew were lost upon re-entry

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© Getty

Below: Curiosity has been exploring Gale crater, which may be an ancient lake

© NASA

IMPORTANT PEOPLE AT NASA

BILL NELSON

Administrator

Nelson served in the US Senate and flew on Space Shuttle mission 61-C in 1986.

"Are we alone? Personally, I don't think we are."

PAMELA MELROY

Deputy administrator

One of only two women to command a Space Shuttle, Melroy spent 38 days and 20 hours in space.

"There'll be excitement, fulfilment, boredom and routine, and even the occasional train wreck."

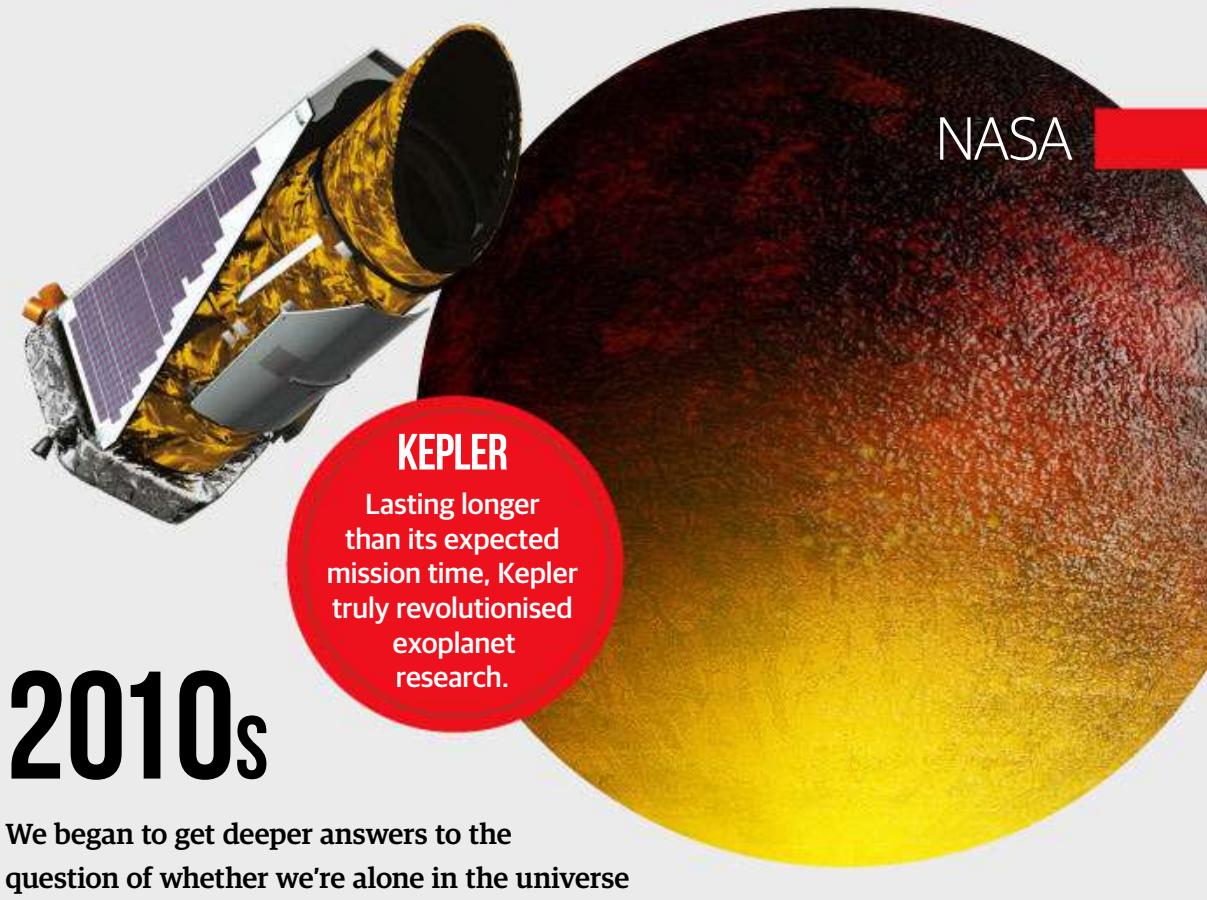
KATHY LUEDERS

Associate administrator of human exploration and operations

The first female head of human spaceflight, Lueders was appointed to the role in June 2020.

"It's exciting to see us maximising the ISS and expanding access to low-Earth orbit."

x3 Images © NASA



NASA

KEPLER

Lasting longer than its expected mission time, Kepler truly revolutionised exoplanet research.

2010s

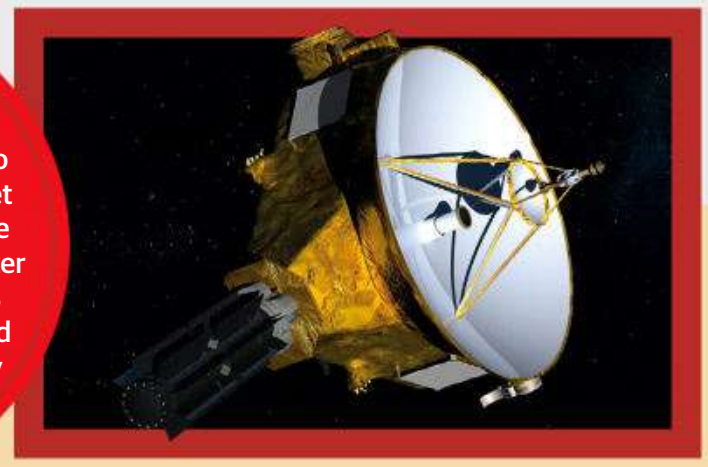
We began to get deeper answers to the question of whether we're alone in the universe thanks to NASA's Kepler space telescope. Launched in 2009, it took until January 2011 to announce the discovery of its first rocky planet beyond our Solar System. What it went on to discover revolutionised our understanding of what's possible when it comes to alien planets. It found exoplanets orbiting their stars in mere hours, others that have two suns instead of one and yet others where the temperature appears to be right to permit the presence of liquid water.

A year after the last Space Shuttle launch in 2011, NASA attempted its most audacious Mars landing yet. The Curiosity rover, currently still hard at work on the Red Planet, is almost double the dimensions of Spirit and Opportunity. Those missions had been deployed using an inflatable cocoon that bounced and deflated to allow the rovers to drive out. Curiosity was too big for that, so it was lowered onto the Martian surface using a futuristic-looking sky crane.

New Horizons reached the dwarf planet Pluto in 2015 after a nine-year voyage out to the region beyond the planets. The vivid images it sent back revealed a surprisingly active world for an object marooned so far from the warmth of the Sun. Curiosity was joined on Mars by the InSight lander in 2018, which is designed to look for marsquakes and probe the Red Planet's inner structure.

NEW HORIZONS

Seven months after the launch of New Horizons, Pluto was demoted to a dwarf planet after similar small bodies were discovered and reclassified. After snapping Pluto's 'heart' on its flyby, the spacecraft continued on to the Kuiper Belt to study 486958 Arrokoth.



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2020s

Martian exploration continues at pace, including dispatching Ingenuity – a helicopter that performed the first powered flight on Mars – from the Perseverance rover on 19 April 2021. We could soon know more about deflecting hazardous asteroids, too. In November 2021, NASA launched its Double Asteroid Redirection Test (DART). By the end of 2022 it will have hopefully collided with the asteroid Dimorphos, nudging it slightly off course.

Hubble's long-awaited successor, the James Webb Space Telescope (JWST), made it into space on 25 December 2021 after decades of wrangling, political setbacks and engineering delays. The unfurling of its sunshield went perfectly, as did the unfolding of its huge mirror. Arriving at its destination in January 2022, it will look back in time to the formation of the first stars and galaxies. NASA is also gearing up for its astronauts to return to the Moon for the first time since 1972. Its Artemis program is set to put the first female astronaut and first astronaut of colour on the Moon in 2025.

NASA has been around for more than six decades and continues to set the benchmark for space exploration. Yet it has faced numerous challenges throughout its long history. It has persisted through the administrations of no fewer than 13 US presidents, each with their own agendas, goals and manifestos.

Now, in the 21st century, it's repositioning itself to work alongside the growing number of private space companies and enterprises, like SpaceX. Given that NASA is ultimately taxpayer funded, it increasingly needs to justify its existence and look for value of money. It also needs to make the case for continued space exploration in the middle of an ongoing climate emergency. The next decade could be as crucial as the last six in terms of NASA's place in the world and beyond.

Above: Webb will view the ancient universe using its infrared eyesight

ARTEMIS

With the aim of putting the first woman and first person of colour on the Moon by 2025, the Artemis program has been in development and testing for a while now. The first crewless mission should fly in the next few months if all goes to plan.

© NASA

NASA'S TOP MISSIONS

NASA has explored every known planet in our Solar System

CASSINI

Launch date: 15 October 1997

End date: 15 September 2017

Description: The first probe to enter Saturn orbit, it dispatched a lander to Titan called Huygens.

VOYAGER 2

Launch date: 20 August 1977

End date: Ongoing

Description: The only probe to visit Uranus and Neptune.

DAWN

Launch date: 27 September 2007

End date: 30 October 2018

Description: The first probe to orbit two extraterrestrial objects, asteroids Ceres and Vesta.

NEW HORIZONS

Launch date: 19 January 2006

End date: Ongoing

Description: The first probe to visit Pluto, it continues to explore the Kuiper Belt.

GALILEO

Launch date: 18 October 1989

End date: 21 September 2003

Description: The probe studied Jupiter and its moons and the asteroids Gaspra and Ida.

NASA

APOLLO 11

Launch date: 16 July 1969

End date: 24 July 1969

Description: The first mission to land astronauts on the surface of the Moon.

MARINER 4

Launch date: 28 November 1964

End date: 21 December 1967

Description: The first successful flyby of Mars, its pictures revealed a dead-looking world.

MARS PATHFINDER

Launch date: 4 December 1996

End date: 27 September 1997

Description: Carried the first Mars rover and first rover outside the Earth-Moon system.

MOON

SURVEYOR 3

Launch date: 17 April 1967

End date: 3 May 1967

Description: The first mission to carry a surface soil sampling scoop to the Moon.

60s

70s

80s

MERCURY

90s

MARS

VENUS

00s

JUPITER

PIONEER 10

Launch date: 2 March 1972

End date: 23 January 2003

Description: The first mission to the planet Jupiter and first to traverse the asteroid belt.

MAVEN

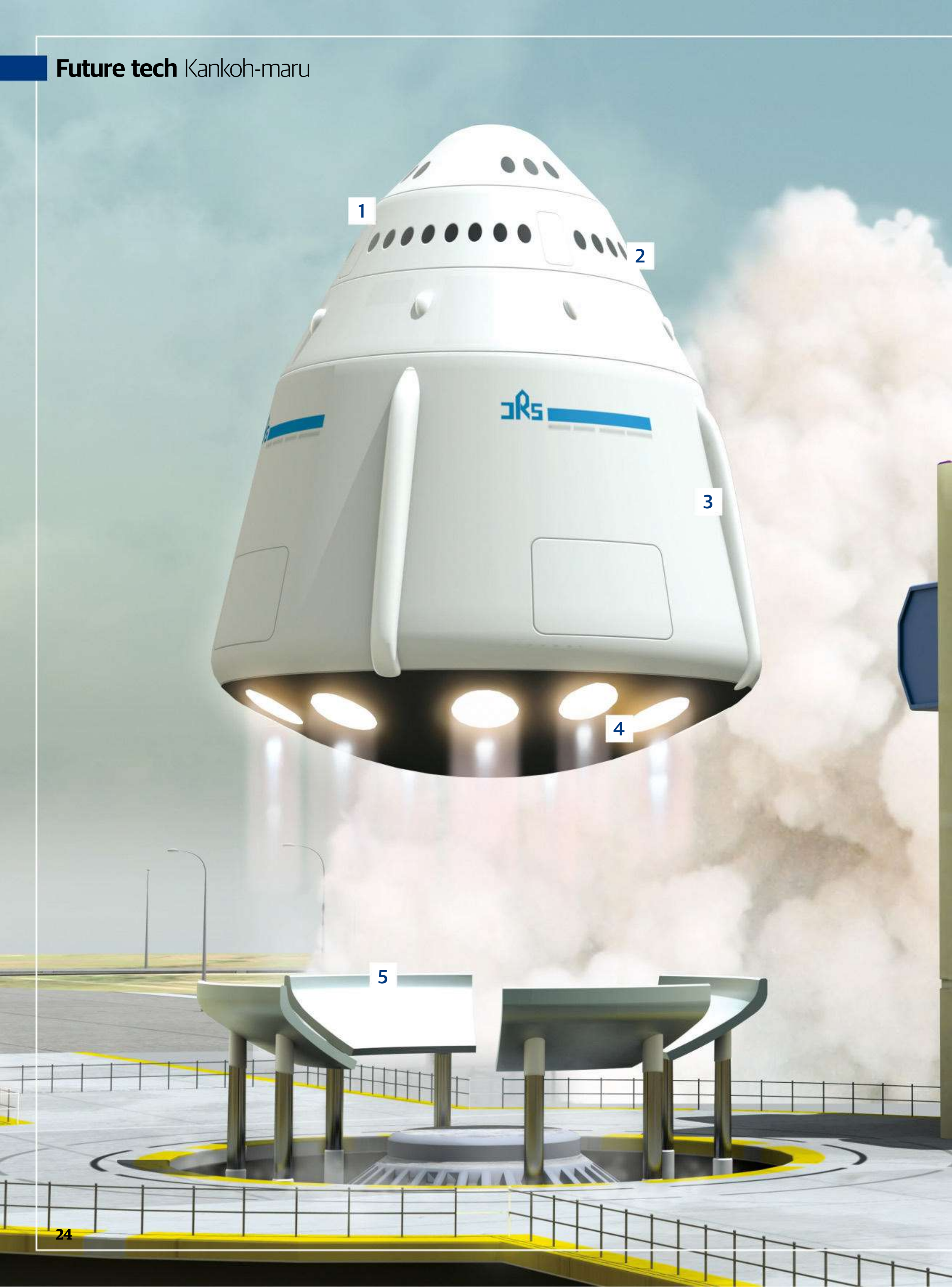
Launch date: 18 November 2013

End date: Ongoing

Description: The Mars Atmosphere and Volatile Evolution orbiter studies how Mars loses its atmospheric gases to space.

10s

© NASA; Getty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KANKOH-MARU

This ambitious reusable spacecraft will be capable of taking 50 people to and from orbit

The Kankoh-maru, named after the steam-powered Japanese Kankō Maru vessel, is ambitious in its design to say the least. If it reaches fruition, this bizarre egg-shaped vehicle will take off and land by VTVL (vertical takeoff, vertical landing) as a single-stage-to-orbit (SSTO) spacecraft. The whole thing is reusable, and with each launch the Kankoh-maru can take 50 people into orbit.

The vehicle was first proposed by the Japanese Rocket Society in 1993. Since then a variety of tests on VTVL vehicles, albeit ones much smaller than the Kankoh-maru, have been carried out to test the feasibility of such a design. The good news? VTVL can successfully take a vehicle into the air and land it safely on Earth. A recent development in this regard is SpaceX's Falcon 9 technology, which the company uses to return rocket stages to Earth after launch. The troublesome news is that to date no SSTO spacecraft has launched into space and landed. That doesn't mean it can't be done, just that building something like the Kankoh-maru would be an engineering challenge the likes of which has never been seen before.

Nonetheless, the design of the Kankoh-maru is certainly intriguing, and it does allude to a future where spacecraft of this sort are in operation. The vehicle, weighing about 550 tonnes, would tower 23.5 metres (77 feet) above the ground and have a diameter of 18 metres (59 feet) at its base. The spacecraft is split into two sections, with a propulsion section at the bottom using four boosters and eight sustainer rockets to provide thrust at sea level and in space respectively. Above the propulsion section is the payload section, with the cockpit sitting at the very top.

The purpose of this spacecraft will be to take a large number of crew into Earth orbit, either to an orbiting space hotel or just for short orbital trips. The ambitious goals of the spacecraft could see tickets falling to as little as $15,000 (£10,900) a head, with over 700,000 passengers a year being taken into space via a fleet of 52 Kankoh-maru craft. Each vehicle would be expected to fly 300 flights a year. While it's unlikely we'll see anything like this any time soon, the design and proposal is ready and waiting if an agency or private company decides to build a one-of-a-kind vehicle like Kankoh-maru at some point in the future.

1 CREW

Two crew – a pilot and a flight engineer – operate this giant spacecraft from a cockpit at the top of the payload section.

2 PASSENGERS

The Kankoh-maru will be able to hold 50 passengers in its interior habitat – a much bigger crew than any spacecraft that has ever flown before.

3 PAYLOAD

The Kankoh-maru can take around five tonnes into low-Earth orbit, which could be a mix of passengers and cargo.

4 PROPULSION

A total of 12 rockets underneath the Kankoh-maru will propel the spacecraft into space.

5 TAKEOFF AND LANDING

The Kankoh-maru will take off and land using its boosters and sustainer rockets. It can refuel at an orbiting hotel prior to landing to eliminate the need to carry all of its required fuel.

"WITH EACH LAUNCH THE KANKOH-MARU CAN TAKE 50 PEOPLE INTO ORBIT"

AR SCAN HERE

© Adrian Mann

INTERVIEW

BIO

Gregory Leonard

Leonard is a senior research specialist at the University of Arizona's Lunar and Planetary Laboratory. In January 2021 he discovered Comet Leonard – the brightest and most anticipated comet of 2021. The comet was spotted, somewhat accidentally, using the Catalina Sky Survey's 1.5-metre (60-inch) telescope at the Mount Lemmon Infrared Observatory, located in the Santa Catalina Mountains in Arizona.

The comet, formally known as C/2021 A1, has since been making its way to the inner Solar System, passing near Earth on 12 December 2021 and Venus on 17 December 2021. On 3 January 2022, Comet Leonard reached perihelion – the closest approach to the Sun in its orbit – at a distance of roughly 90 million kilometres (56 million miles).

© Catalina Sky Survey/University of Arizona

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GREGORY LEONARD

"WE DO OCCASIONALLY STUMBLE INTO UNKNOWN COMETS"

Comet Leonard's discoverer explains how the unusual object was found – and what it's told us about these dirty snowballs

Interviewed by Samantha Mathewson

How did you discover Comet C/2021 A1?
I'm an astronomer with the Catalina Sky Survey, a NASA-funded project based out of the University of Arizona, and we're directed to discover and track near-Earth asteroids – the kind of asteroids whose orbits can bring them close to Earth and potentially impact the planet. I discovered Comet C/2021 A1 Leonard – also known to the world as Comet Leonard – on the morning of 3 January 2021. It was a serendipitous, or incidental discovery in one of our standard survey fields, looking for near-Earth asteroids.

We do occasionally stumble into unknown comets, and that's exactly what Comet Leonard was. I saw the object not as a point or star-like object, like most asteroids would appear to us; this one had the telltale fuzzy coma that comets have – the coma is that thin, tenuous atmosphere that forms around the nucleus of a comet when it gets close enough to the Sun to excite and sublimate, or boil off, the ices that the comet is made of. In addition to seeing that thin coma, or that fuzziness around the comet, I also detected a little stubby tail, and that, of course, is another telltale sign that it's likely a comet.

You mentioned that the comet's discovery was serendipitous, or unexpected. Can you explain why?
This comet was my tenth comet discovery, and since that time I've discovered three more, so there are actually 13 Comet Leonards out there. Now, I don't name these comets. They automatically assume the name of the discoverer, which in all these cases was me over the last six years. They are unexpected [because] we are looking for near-Earth asteroids, and it's only on occasion that we stumble into what appears to be a comet, and then we report those to the IAU Minor Planet Center at Harvard, Massachusetts, which is the clearing house for all asteroid and comet observations.

What was unexpected about this comet was its orbit. Unlike most other comets that are discovered throughout the year, this comet is on an orbit that brings it relatively close to the Sun and Earth – close enough for it to potentially be seen from the backyard by casual observers.

What's the comet's origin and composition?
Its origin is likely from a distant sphere of comets called the Oort Cloud, which is a vast reservoir of millions, or perhaps billions of comets. The Oort Cloud is really far [from the Sun]. It's at least 5,000 astronomical units – an astronomical unit is the Sun-Earth distance – and may go out as far as 100,000 astronomical units.

This comet likely came from the inner Oort Cloud, 3,700 astronomical units away, and it's what we call a long-period comet. The comet has been inbound, on this leg, for the last 40,000 years. If we trace that back, it's really been on an 80,000-year orbit. The last time it would've come [into] the inner Solar System would have been 80,000 years ago.

What it's made of is still to be determined. There are most likely telescopes around the planet that have been looking at the spectra from the comet, and I think we'll see some papers and research

> WHEN WE LOOK AT COMETS, WE'RE REALLY LOOKING AT PIECES OF OUR OWN HISTORY

come out in 2022 talking a little bit more about exactly what [the comet] is made of. I'm sure we'll see some of the usual comet suspects, and that would be water ice, carbon dioxide, carbon monoxide, some ammonia and maybe some other exotic compounds as well.

What's interesting is that when I discovered the comet, it was 450 million miles [724 million kilometres] away – about the distance that Jupiter orbits the Sun – and the fact that I spotted a tail is interesting [because] water ice will not sublimate at that distance, in that cold region of space. So it's some other compound that would likely have been boiling away and sublimating, perhaps carbon dioxide or carbon monoxide. I think this comet will be observed as far out as it can be observed by telescopes, and we're going to get a better idea about what it's composed of.

Since its discovery, what have we learned from this comet, either about comets in general or about the early Solar System?

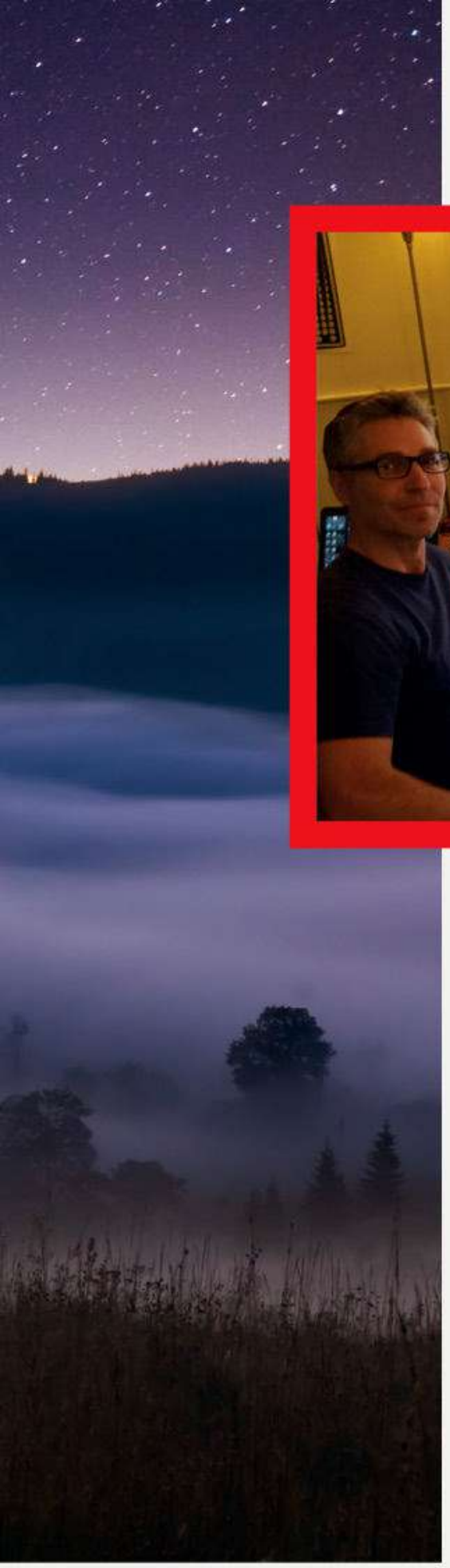
Once we better understand the exact composition of this comet, it will give us some clues and hopefully patch in some holes of knowledge about the conditions that existed at the time of the formation of our Solar System. Comets are very, very pristine, and they carry this information with them. These were basically unaltered, unaffected, primitive bodies left over from the formation of all the planets. This is why they are really exciting for astronomers and researchers to scrutinise to better understand where we came from.

Comets, in addition to the near-Earth asteroids that my project looks for, impacted Earth billions of years ago and likely brought some amount of water, contributing to our oceans and freshwater resources. When we look at comets, we're really looking at pieces of our own history, our own formation of our climate and maybe even some of the constituents of what we ourselves are made of.

How did Comet Leonard make its way into the inner Solar System?

The comets that reside in the Oort Cloud are held in a gravitational balance between the feeble tug of the Sun's gravity and the entire gravitational tug of our galaxy. With just the slightest bit of gravitational nudging, or disturbance in the galaxy, these comets can either sort of fall out of the Oort Cloud or they can begin their long journey inwards towards our Sun – and that's exactly what happened in the case of this comet.

That's how many long-period comets get their beginning: they're gravitationally nudged



© Getty

© Catalina Sky Survey

Above: Leonard at the Catalina Sky Survey observing station

Left: Comet Leonard was a truly majestic sight for observers

or perturbed, and the Sun wins the battle. They start cascading inwards towards the Sun, taking thousands and thousands of years to do so.

In this case, we have to say hello and goodbye to Comet Leonard. This is its final passage [in our Solar System]. It has an escape velocity, moving at 44 miles per second, or 70 kilometres per second, which is sufficient for it to be flung out from our Solar System forever.

Just like it takes rockets a certain minimal velocity to escape the gravity of Earth, the Solar System also has an escape velocity. Comet Leonard has that velocity, so once it passes close to the Sun, it will, from that point forward, be moving away. The comet will leave our Solar System and travel for millions of years, perhaps to stumble into some other stellar system a long time from now.

The comet's most recent planetary flyby was at Venus on 17 December 2021. What impact do you think the comet had on the planet?

That remains to be seen. One thing that we will be looking for is the potential for Venus to pass through the dust stream left by the comet. The comet is going to go past Venus' orbit, and then Venus is going to pass through that area. It's possible that Venus may experience a meteor shower from the dust particles left in the wake of Comet Leonard's passing. It's possible with the geometry of Earth that it could be visible with telescopes from Earth. The Japanese Space Agency, JAXA, has an orbiting spacecraft around Venus right now. It's called Akatsuki, and it's on a Venus climate mapping mission. However, there may be an opportunity for some of the sensors on Akatsuki to look for potential meteors entering the upper Venusian atmosphere.

To be an observer on the nightside of Venus as Comet Leonard cruised by, it would have been breathtaking to see. It passed about 2.6 million miles [4.2 million kilometres] from Venus on 17 and 18 December, which sounds like a long way – and for us on Earth, it is – however, that's really just a cosmic whisker. It just missed almost clobbering Venus by a couple of days. The Earth flyby was about 22 or 23 million miles [35 or 37 million kilometres], so it was ten times closer to Venus in its flyby there.

What can we expect as the comet heads towards the Sun?

I think the only thing that's consistent about comets is their utter unpredictability. A wise comet hunter and discoverer once said comets are like cats: both have tails and both do precisely what they want – and that's true. It's likely that [Comet Leonard] is going to dim. And that's not so much because it's getting close to the Sun, [but because] Earth is now really receding. Both objects are receding from one another. Typically, when a comet approaches the Sun, we tend to see a brightening. If Earth wasn't moving away from [the comet], we would likely see just that. But we're likely to see it dim only because we're moving away. However, there's always a chance that as it nudges closer to the Sun there could be some increased activity, maybe some outgassing or some jetting – some outburst that occurs that will brighten the comet's appearance from Earth.

What causes those outbursts?

As a comet approaches the Sun, you'll get the ices sort of violently sublimating and boiling away. If there's a pocket of material that's suddenly released, which releases pressure, that could be enough to kind of pull the comet apart – they are very fragile objects. Comets have a really low density. The density of water is one gram per cubic centimetre, and the density of a comet is a third of that, so these are very fragile objects and any forces at all, be they gravitational or related to the volatile release from these ices blowing away, is enough to expose more material and have that material boil away. This could be one cause for a brightening – for an outburst of the comet.

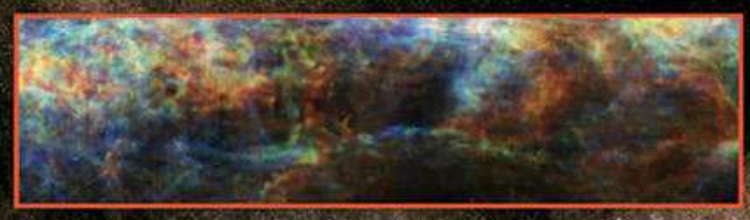
Another recent effect is a phenomenon known as forward scattering. The comet was very close in angle to the Sun, and the sunlight shining through, essentially backlighting all the dust in the tail, has been known to enable comets to brighten considerably by one, two or even three magnitudes. It can temporarily brighten for 12 or 24 hours.

So we won't see the comet again because of its escape velocity. Where do you think it's going to go?

I haven't seen any projections as to which direction it's flying off into our galaxy. It'll be fun to see what potential star system it could bump into many, many years from now. Suffice to say that this is the final visit [to our Solar System].

Right: Comet Leonard visible in an image captured by a small Chinese satellite with a backdrop of a beautiful aurora

© Origin Space



A GIANT ATOMIC CLOUD CALLED ‘MAGGIE’ LIVES IN THE MILKY WAY

Astronomers have discovered a giant filament stretching across our home galaxy

Reported by Chelsea Gohd

Stretching thousands of light years across the Milky Way, a newly discovered filament of hydrogen named Maggie is one of the biggest structures ever discovered in our galaxy, and researchers think there could be others like it.

A group of astronomers led by researchers at the Max Planck Institute of Astronomy in Germany has spotted something strange on the other side of the Milky Way: a massive filament of hydrogen gas. Hydrogen is both the simplest and the most abundant element in the universe. But hydrogen clouds like this filament can be tough to spot amid the interstellar medium, the matter and radiation that lies between star systems in a galaxy.

'Maggie', which is made up almost entirely of atomic hydrogen gas, is a whopping 3,900 light years long and 130 light years wide. For reference, a single light year is about 9.46 trillion kilometres or 5.88 trillion miles.

"In contrast, the largest known clouds of molecular gas typically extend 'only' about 800 light years across," according to the Max Planck Institute of Astronomy.

> "THE FILAMENT EXTENDS ABOUT 1,600 LIGHT YEARS BELOW THE MILKY WAY PLANE" JONAS SYED

In this new study, the team of astronomers used data from the HI/OH/Recombination line survey of the Milky Way, also known as the THOR survey, to investigate Maggie and shed light on large clouds of hydrogen like it.

The team discovered Maggie, and with their work were able to see how far it stretches, the velocity of the hydrogen gas making it up and more. The astronomers were even able to determine Maggie's distance from Earth, which they estimate is about 55,000 light years. Typically, it's very challenging for astronomers to detect large hydrogen groupings like this because they don't stand out against the interstellar medium. However, Maggie's unique location helped make it visible.

"The location of this filament has contributed to this success. We don't yet know exactly how it got there. But the filament extends about 1,600 light years below the Milky Way plane," said Jonas Syed, a PhD student at the Max Planck Institute of Astronomy, who added that this location makes it possible for researchers to see radiation emanating from the hydrogen.

Understanding more about Maggie and other structures like it is a major step towards better understanding star formation, as hydrogen is the building block of stars. There remain additional questions about this large filament, like where it came from, but this discovery could lead to many more. "While Maggie's origin remains unclear, we hypothesise that Maggie could be the first in a class of atomic clouds that are the precursors of giant molecular filaments," the researchers wrote.

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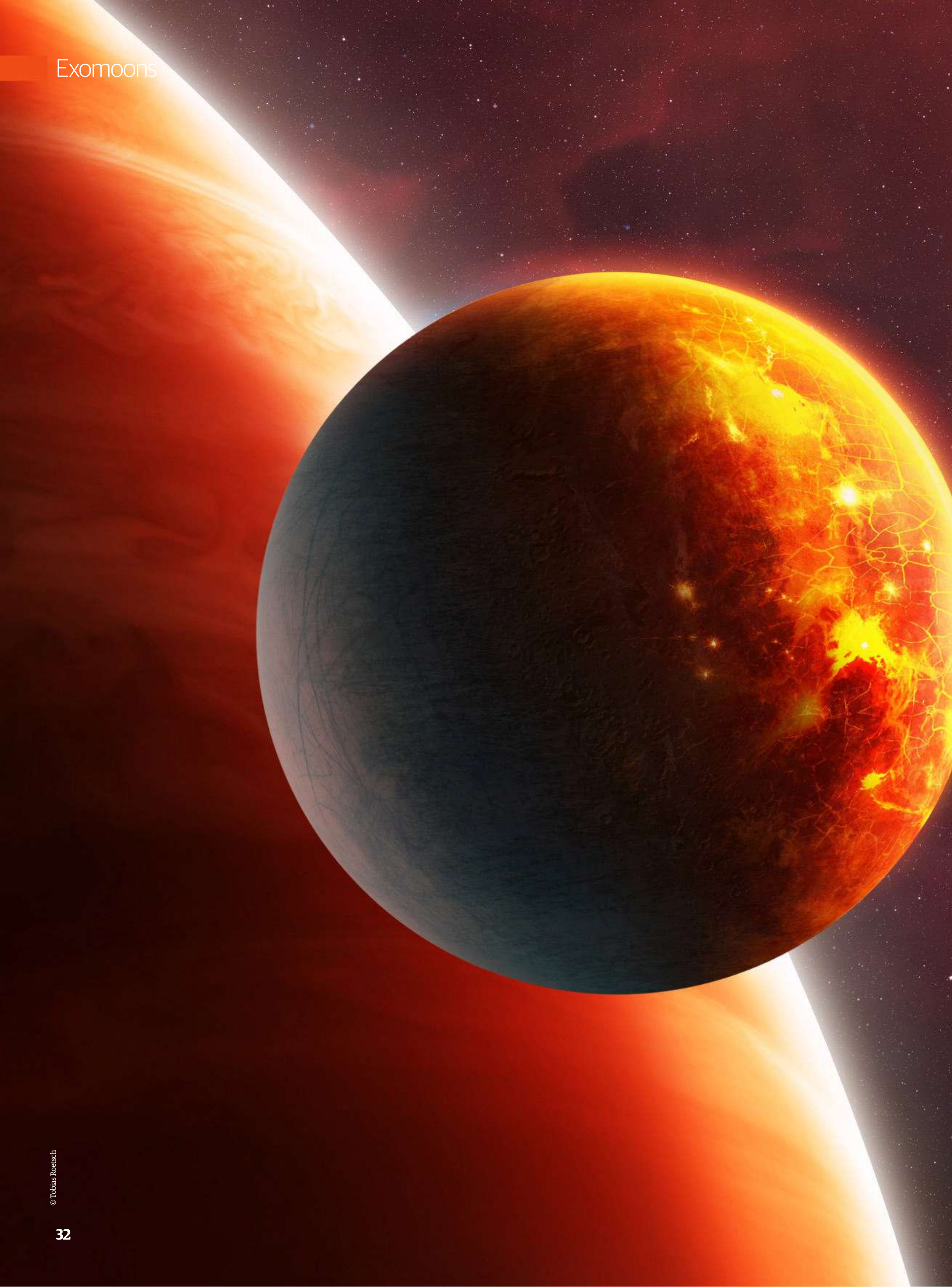

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FINDING AND DEFINING EXOMOONS

As our catalogue of exoplanets grows, the hunt is on for moons around distant worlds

Reported by Robert Lea

Astronomers may have finally discovered a moon orbiting around a planet outside our Solar System. The development could have important implications for our understanding of how planetary systems evolve, as well as indicating how typical the planets of our Solar System are. Since the first discovery of planets around stars other than the Sun was made in the early 1990s, our catalogue of planets outside the Solar System has burgeoned, now containing over 4,000 confirmed worlds. One of the most important aspects of our investigation of these extrasolar planets – or exoplanets – is the assessment of how similar or diverse they are in comparison to the planets of the Solar System.

It's unsurprising given how Earth's own Moon has dominated our imagination and played a vital role in both astronomy and humanity's exploration of space that the hunt for moons around these extrasolar worlds – or exomoons – is a subject of intense interest. This is compounded by the fact that moons are abundant in the Solar System, with an average of 20 moons for each planet. And we have no reason to believe that our planetary system is unique in this respect, making the elusive nature of exomoons confusing and frustrating.

To understand why the discovery of exomoons may be important, it's worth considering just how influential some researchers believe our natural satellite was to the development of life on Earth. This is coupled with the fact that many scientists theorise that if life exists elsewhere in the Solar System, aside from Mars, the most likely places to find it would be on the moons of gas giants Jupiter and Saturn, with the icy moon Enceladus being a particularly enticing suspect. This means that exomoons could be a target for habitability investigations in their own right, especially when they orbit gas giants and could potentially be the size of Earth, or even larger.

Determining if an exoplanet is orbited by a moon could be important for investigations of that planet's habitability potential in another way. For rocky terrestrial exoplanets in the habitable zones of their stars – the area that has the right temperature to allow for the existence of liquid water – an undetected moon may add an additional source of thermal or reflected light that hinders the determination of characteristics belonging to the planet itself.

Observations of our Solar System, in which moons are plentiful, suggest that such objects should be extremely common throughout other systems. However, until recently these exomoons have proven to be particularly elusive. This could be because our detection methods are not sensitive enough as of yet to spot these moons outside the Solar System, or because moons are less common in other planetary systems for some reason. Determining which of these possibilities is correct is an important and missing aspect of our ongoing investigations of extrasolar planetary systems.

© Alamy

Left: Zodiacal light over La Silla Observatory in Chile

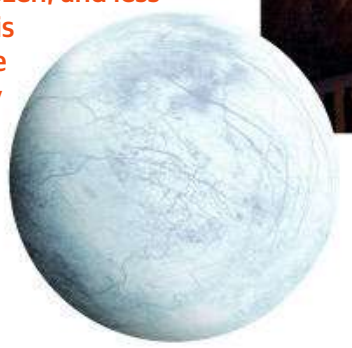
Below: If alien worlds are anything like those in our Solar System, moons should be plentiful

TYPES OF EXOMOON

How we can categorise the alien moons we expect to find

SNOWBALL EXOMOON

A snowball exomoon is one where the entire moon is permanently frozen, and less than one-tenth is habitable. These worlds are likely to have been born far from their stars, or were perhaps moved there from a position nearer the star.



HABITABLE EXOMOON

Habitable exomoons are defined as those where at least a tenth of the surface could support liquid water. These will need to be in the star's habitable zone, as well as the right distance from the planet, but could be great bets for finding life elsewhere.

TRANSIENT EXOMOON

A transient exomoon is said to be sort of habitable, but its habitability changes dramatically over time. The idea that a moon may shift in and out of habitability will need careful consideration when we look for and study exomoons.

HOT EXOMOON

Researchers Duncan Forgan and Vergil Yotov came up with a system for classifying exomoons in 2014. One class was a hot exomoon, defined as one with an average surface temperature of more than 100 degrees Celsius (210 degrees Fahrenheit), with less than one-tenth being habitable.

Discovering exoplanets, though not easy, relies on several tried-and-tested methods. The most powerful of these is the transit technique – used by both Kepler and NASA's Transiting Exoplanet Survey Satellite (TESS) – which hinges on observing the tiny dips in light from a distant star as an orbiting planet crosses its face. The transit technique used to detect exoplanets is also being used to hunt for exomoons, though undeniably with less success. To understand why the transit technique – the most successful exoplanet-hunting method, yielding thousand of discoveries – may not be as successful in detecting exomoons, consider what astronomers must spot to indicate the presence of a lunar body.

Like cosmic nesting dolls, to spot an exomoon using the transit method, astronomers would need to observe a transit within a transit – a situation in which as a planet transits its star, its moon is also visible transiting the star's face. Even if this occurred and we were lucky enough to catch it, the observation would have to be made with equipment sensitive enough to spot the exomoon and distinguish the dip in light it causes from the dip in light caused by its parent planet.

Furthermore, even large exoplanets cause just tiny dips in the light signature of their parent stars, so imagine how small a reduction in light would be when caused by an exomoon, being much more diminutive than its host planet. Another issue with detecting exomoons is related to the kinds of exoplanets that the highly successful transit method is best at spotting, as these may not be planets that are best suited to hosting moons. The transit method excels at discovering large planets that are very close to their parent stars. This is based on the simple logic that the larger a planet is, and the closer it exists to its star, the more light it will block when it crosses that star's face. This creates a more prominent signal for astronomers to identify and distinguish from background noise.

© Getty

Extremely proximate planets are often tidally locked to their stars – as is the case with Mercury – and thus their rotation slows. This proximity can mean that one face of the planet permanently faces its star, becoming blisteringly hot, resulting in a world with a permanent dayside and nightside. But it has another effect, and it's one that has a significant impact on the chance of an exoplanet holding onto natural satellites. When orbiting around a planet, a moon or any other natural satellite will often have a synchronous orbit. For an orbit to be stable, this needs to be within what is called the Hill sphere – the hypothetical region around a planet in which it dominates the gravitational attraction of objects. For exomoons, this is a limiting radius at which they may be gravitationally bound and remain stable.

As the rotation of a planet is slowed, the synchronous orbit is pushed out, away from that world. For tidally locked exoplanets that barely spin – if at all – this orbit is pushed beyond the Hill sphere. This means that any potential moons within the Hill sphere will not have a stable synchronous orbit and will thus spiral towards the planet. Meanwhile, moons outside the Hill sphere will likely escape the planet due to the lack of gravitational influence they experience, thus never reaching the synchronous orbit.

There is another hindrance to exomoon possession experienced by exoplanets that exist close to their parent stars. Many of these

HUNTING FOR EXOMOONS

Kepler helped us find many exoplanets that may host natural alien satellites

1 SUNSHADE

As the name suggests, the sunshade blocked the Sun's rays from the photometer so it could observe the universe without being blinded or obstructed.

2 PHOTOMETER

The most important instrument on Kepler was the photometer, which looked at stars to notice dips in their light as planets pass in front, known as a transit.

3 REACTION WHEELS

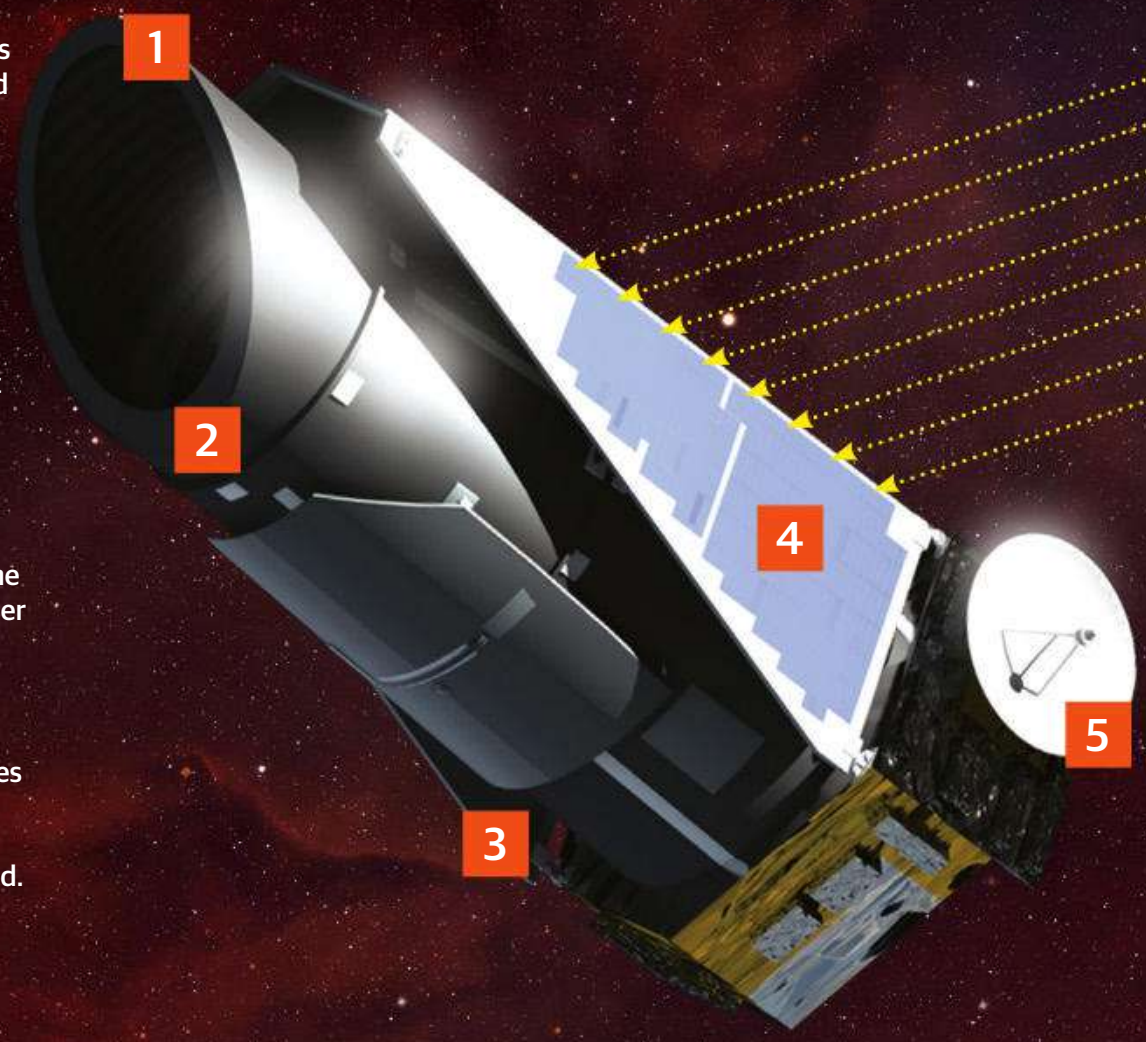
These were used to point the telescope at distant stars in order to find planets.

4 SOLAR ARRAY

Kepler had to roll 90 degrees every three months to keep its solar panels pointed at the Sun and keep the telescope powered.

5 HIGH-GAIN ANTENNA

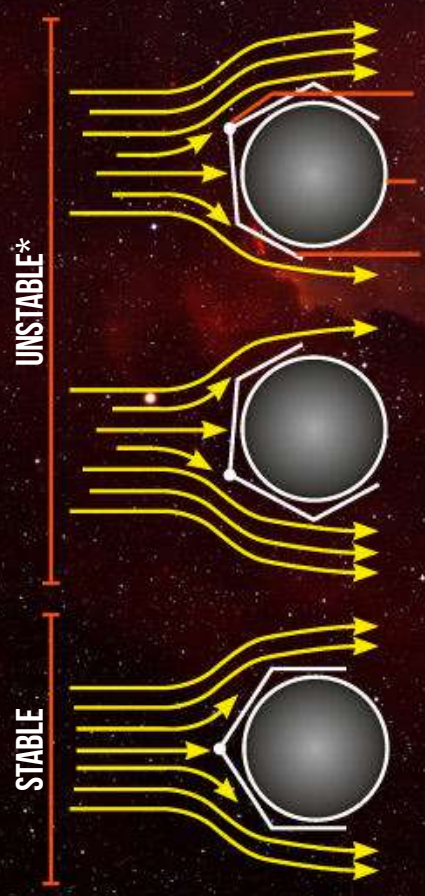
This was used to communicate with Earth, receive commands and send back data on any exoplanets Kepler found.

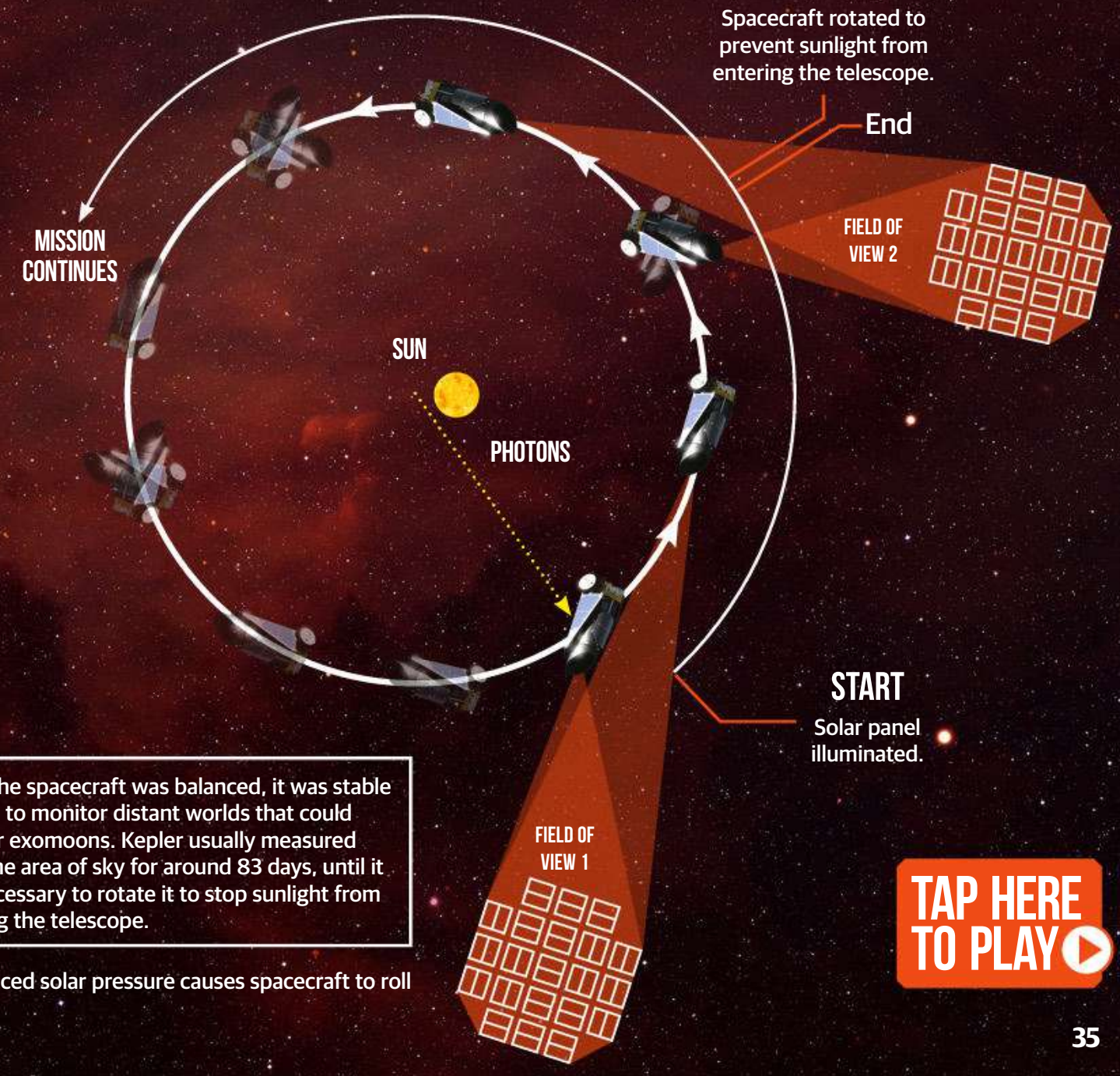


SOLAR BALANCE RIDGE

Photons in light emitted by the Sun exerted pressure on the Kepler space telescope, allowing the spacecraft to be properly balanced against the pressure.

TOP-DOWN VIEWS OF THE SPACECRAFT





When the spacecraft was balanced, it was stable enough to monitor distant worlds that could harbour exomoons. Kepler usually measured the same area of sky for around 83 days, until it was necessary to rotate it to stop sunlight from entering the telescope.

* Unbalanced solar pressure causes spacecraft to roll

TAP HERE TO PLAY

exoplanets orbit their stars with a period of a few days, while others take just hours to circle their parent star. In simulations published in May 2021, researchers from the University of Groningen used a simplified model of one exoplanet, orbiting a single star and possessing a single exomoon, to determine how likely such a world would be to hold its moon as different parameters were altered.

Watching the model evolve over a period of 10 billion years, the team tested how changing the masses of the components of the system changed the prospects of the planet holding onto its moon. They also adjusted the distance at which the exoplanet orbits its star. This highly simplified model suggested that the orbital period of the exoplanet was key to retaining an exomoon. For exoplanets with orbits ranging from 300 days – similar to the orbit of Earth around the Sun – to ten days, the survival rate of exomoons dropped from 70 down to 0 per cent. The team's model suggests that for planets so close to their host stars that they complete an orbit in less than ten days, there was no stable orbit for a moon.

These results reflect observations of our own planetary system, with the two innermost planets – Mercury and Venus – lacking moons and Earth possessing its own large natural satellite. Jupiter and Saturn, both larger planets that are more distant from the Sun, host large collections of moons. Because the majority of the planets in our current exoplanet catalogue were discovered using the transit method, and this method favours planets close to their parent stars, all this means is that there's a bias in the exoplanet catalogue that disfavours planets with exomoons. Yet despite the difficulty associated with detecting exomoons, several possible exomoon identifications have been made. But these potential exomoon detections are still controversial.

In January 2022, a new paper published in the journal *Nature Astronomy* revealed that astronomers had discovered a signal that indicates the presence of a moon outside the Solar System. The discovery was made during an investigation of observational data of 70 suspected massive and cool exoplanets that cross – or transit – the face of their parent stars. These exoplanet candidates had been discovered by the Kepler space telescope, which launched in 2009 and was retired in 2018. In this survey, the research team discovered just one signal that could indicate the presence of an exomoon, which has been named Kepler 1708b-i.

The potential exomoon has a proposed radius around 2.6 times that of Earth's. It orbits a world about the size of Jupiter that takes approximately 400 days to complete an orbit of its star. Whether scientists come to consider Kepler 1708b-i to be the first detected exomoon hinges on further investigation of a signal determined by the same group of astronomers in 2018. It's an observation that has been the subject of intense debate in scientific circles.

In a separate paper published in *The Astrophysical Journal*, a team of astronomers revealed a signal that could indicate the presence of an exomoon around the exoplanet Kepler-1625b, a Jupiter-sized gas giant orbiting a yellow star over 8,000 light years away from Earth. The team spotted the telltale dip in light caused as an object

HOW TO FIND AN ALIEN MOON

The different methods being used to hunt for exomoons

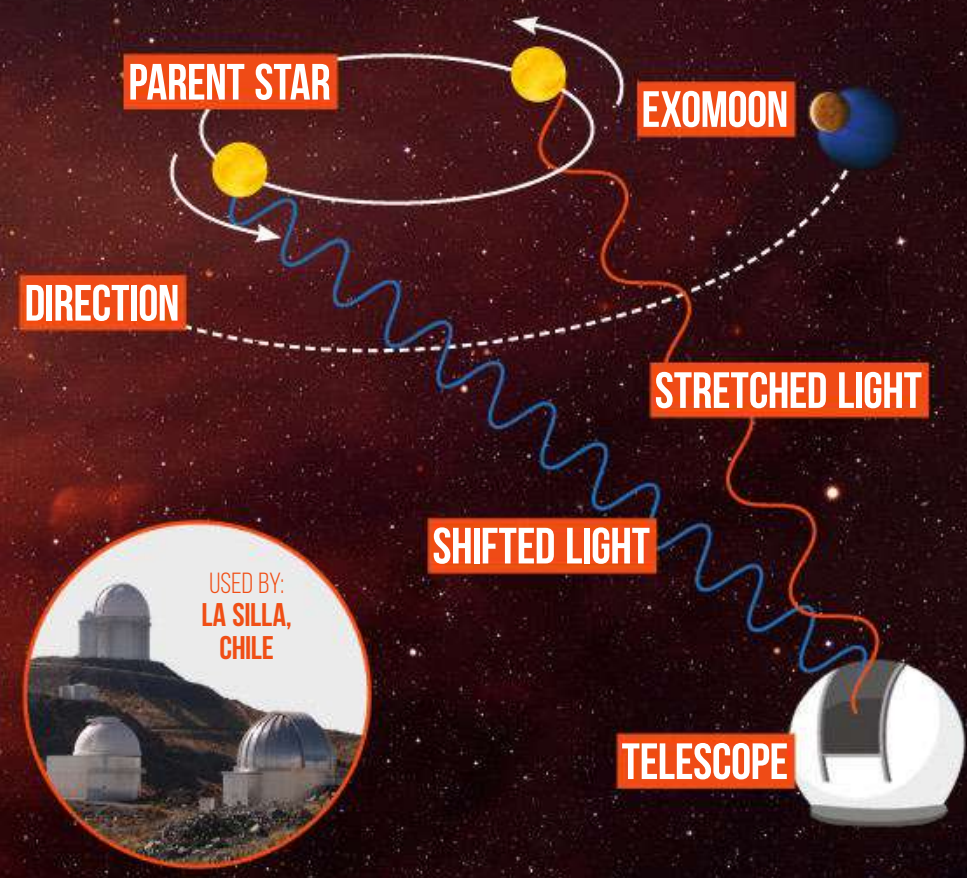
TRANSIT TIMING METHOD

The transit timing method works by measuring a change in the regular transit of a planet. As a planet swings around a star, if there are other objects in its vicinity then it can affect how often a transit is completed. This often indicates the presence of other planets in the system, but in theory the method could be used to hunt for large exomoons as well, revealing their tug on their parent planets. It's hard to distinguish between an exoplanet and an exomoon via this method, though, so it might be difficult to make a discovery with it.

© NASA

RADIAL VELOCITY METHOD

When an exoplanet orbits a star, its gravity can cause a tug on the star, making its presence noticeable to us on Earth. The star's spectrum of light is shifted to the blue end of the spectrum if the planet's coming towards us, and the red end if it's going away. Using this method, some characteristics of the planet can be determined. Like the transit timing method, it's thought that the same principle could be applied to exomoons, noticing their effect on a planet. Again, though, the effect is so small that it would be hard to find exomoons using this method.



crosses the face of a star, suggesting that it was possibly caused by an exomoon, which was given the designation Kepler-1625b I. The observations made by the team – collected with both the Kepler and Hubble space telescopes – were reassessed the following year by two separate teams of researchers. Both teams were sceptical that an exomoon had been detected around Kepler-1625b, albeit to varying degrees.

In a paper published to **arxiv.org** on 25 April 2019, one set of researchers, including Harvard-Smithsonian Center for Astrophysics astronomer Laura Kreidberg, failed to see a moonlike dip in the initial data. They concluded that the light curve of the star Kepler-1625 best conformed to a star transited by a planet alone. A second independent team of scientists, including Max Planck Institute for Solar System Research astronomer René Heller, was only slightly more optimistic. They analysed the same data, finding that signs of Kepler-1625b I were inconsistent.

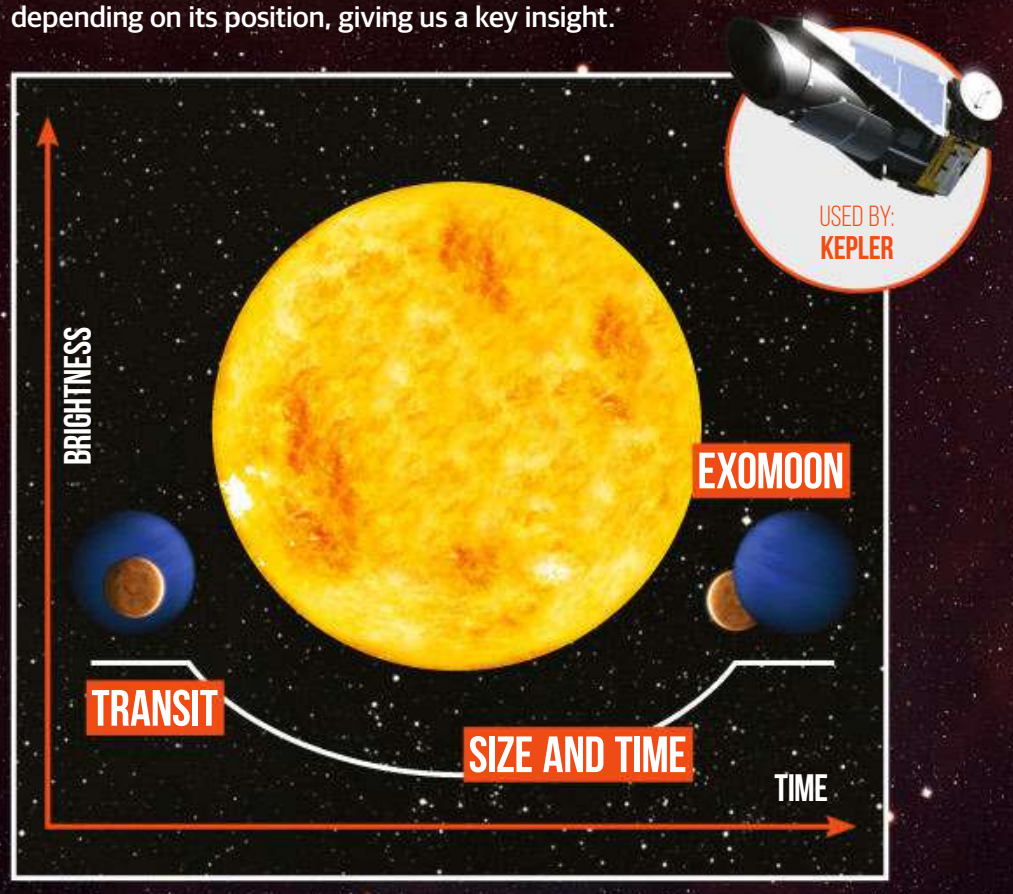
In a paper published in *Astronomy & Astrophysics*, Heller and his colleagues point to

Right: With so many stars in our galaxy alone, there surely must be an exomoon out there

Source: Wikipedia Commons © ScottRak

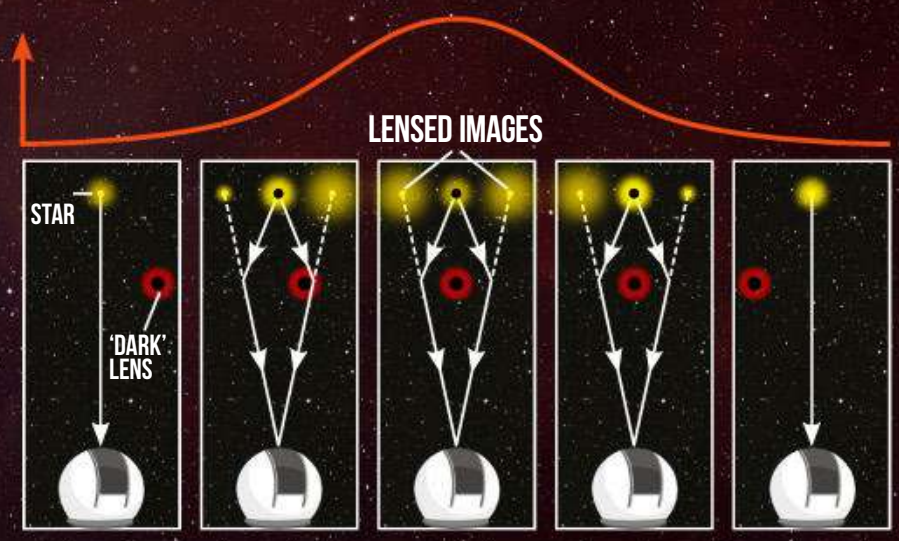
TRANSIT METHOD

Many exoplanets have been found using the transit method. As a planet periodically orbits its star, it causes a dip in the star's light – or flux – if it crosses our line of sight. Measuring this dip, we can then determine the orbital period and even the size of the planet. The same method could also be used for exomoons, noticing the combined dip produced by both the moon and its planet. Indeed, as the moon will be moving around the planet, it may block a different amount of light depending on its position, giving us a key insight.



MICROLENSING

Gravitational microlensing is essentially the result of an object in the universe magnifying a much more distant object. For example, an intermediate star can boost the light of a more distant galaxy, although any given event will occur only once. If the intermediate star has a planet orbiting it, then the effect is altered, and the presence of the planet can be deduced. More recently, it has been suggested that this same method could be used to detect exomoons.



LIGHT
The light from a distant star travels and is picked up by telescopes.

LENSING
The star's light is bent around a massive foreground object.

DOUBLED
The effect causes us to see multiple versions of the distant star.

RING
The effect can cause a ring of light known as an Einstein ring.

UNIQUE
These events only happen once, so there's no opportunity for a repeat.

unknown systematic errors in the Kepler and Hubble data making the finding unreliable, writing that: "Although we find a similar solution to the planet-moon model to that previously proposed, careful consideration of its statistical evidence leads us to believe that this is not a secure exomoon detection."

With more and more exoplanets being discovered, a picture has developed of a universe that is far more varied in terms of worlds than we previously believed. Astronomers have discovered examples of planets for which there are no analogues in our increasingly mundane Solar System. This includes exoplanets like hot Jupiters, those larger than the Solar System's most massive planet which exist so close to their stars they whip around in days or even hours, and rogue planets that wander the galaxy alone, separated from their parent stars. There's a chance that as we discover more exomoons this diversity will be continued through to these smaller bodies, further revealing that the universe can be a strange place.

One exomoon candidate suggested recently is an example of this, and it could provide a solution to a long-standing astronomical mystery. For some time now astronomers have observed the dimming of a distant star called KIC 8462852, or Tabby's Star as it's more commonly known. Many possible mechanisms have been suggested for this often abrupt dimming, ranging from the relatively mundane, like obscuration by dust, to the more 'out there' like black holes, obscuring comets and even to the seemingly fanciful notion of alien 'megastructures'.

In a 2019 paper published in the *Monthly Notices of the Royal Astronomical Society*, it was suggested that the dimming could be the result of a melting exomoon. The authors of the study, including University of Columbia astrophysicist Brian Metzger, posit that this exomoon, composed mainly of ice and rock, is evaporating, and in the process is spewing off material that obscures the light from the star. Not only would this explain the gradual dimming of Tabby's Star that saw it drop in brightness by about 14 per cent between 1890 and 1989, it could also explain random or sporadic fluctuations in the star's brightness of between 1 and 22 per cent. The team also considered that this exomoon may have been detached from its exoplanet host by powerful tidal interactions with the parent star. This interaction, which could have seen the exoplanet destroyed, may have placed the moon in orbit around Tabby's Star, where it began to slowly disintegrate.

Another extreme exomoon candidate spotted in 2019 could be volcanically active like Jupiter's moon Io. Located in the exoplanet system of WASP-49b, astronomers discovered a signal that could indicate a dangerous volcanic moon with a molten surface of lava – almost a lunar version of

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Above: Illustration of a rocky world with two exomoons in orbit

Right: The Keck Observatory in Hawaii is involved in the hunt for exoplanets – and by extension their moons

EXOMOON CANDIDATES

There are a few examples that need further study for confirmation

KEPLER 1708B-I

© Helena Valenzuela Widerström)

Distance from Earth: 5,436 light years

Host planet: Jupiter-sized planet Kepler 1708b

Host star: F-type star Kepler 1708

Exomoon size: Mini-Neptune

Discovered: 2022

KEPLER-1625B I

© NASA/ESA

Distance from Earth: 8,154 light years

Host planet: Jupiter-sized gas giant Kepler-1625b

Host star: Kepler-1625 has a similar mass to the Sun but is 70 per cent larger

Discovered: 2018

Size: Neptune-sized

WASP-49B'S 'EXO-IO'

© University of Bern, Illustration: Thibaut Roger

Distance from Earth: 635 light years

Host planet: WASP-49b a gas giant with a mass 0.37 times that of Jupiter and a similar radius

Host star: WASP-49, a yellow dwarf main-sequence star

Size: Unknown

Discovered: 2022

WHY OUR MOON IS IMPORTANT

From protecting us from asteroids to creating tides on Earth

IT LIGHTS UP THE NIGHT SKY

It's not always bright, but when it is the Moon can provide an excellent source of light at night, useful not only for humans but for animals as well.

IT KEEPS US SAFE FROM ASTEROIDS

The Moon plays a role in keeping us safe from impacts, either deflecting asteroids or taking hits, although the extent of this is debated.

IT CREATES TIDES ON EARTH

Without the Moon, we wouldn't have lunar tides, one of the drivers for spreading nutrients through the ocean, and life would struggle to survive.

IT KEEPS OUR PLANET STABLE

One of the Moon's most important facets is that it stops our planet wobbling too much on its axis, keeping us stable as we orbit the Sun.

IT SLOWS DOWN OUR PLANET

Without the Moon, our planet would rotate a couple of seconds faster every 100,000 years. Over Earth's history, this would amount to a day shorter by several hours.

© Alamy

the super-Earths that orbit their stars at extremely close proximities. The team behind the discovery, who originate from the University of Bern, suspect that the exomoon orbits a hot Jupiter that orbits its star with a period of just three days. Evidence of the exomoon was provided by observations of sodium gas around WASP-49b, located 635 light years from Earth, at an anomalously high altitude. The astronomers also discovered a further four systems that could host similar evaporating exomoons. As is the case with the other exomoon candidates, the confirmation of these exomoons may well rely on further investigations of the planetary systems in question.

Set to be instrumental in this is the James Webb Space Telescope (JWST), launched on 25 December 2021. With future projects like the JWST opening up opportunities to discover exomoons in distant planetary systems, one possible outcome of a deeper study of exomoons may be the revision of what we think of as a moon.

As exomoon discoveries continue, the definition of what we call a moon could become blurred in a similar way to how brown dwarfs have caused us to question the boundary between planets and stars. Often described as failed stars due to the fact they lack the mass to trigger the nuclear fission processes that define stars, brown dwarfs could possess bodies that orbit them. But if brown dwarfs are classed as planets rather than stars, shouldn't we then define the bodies in orbit around them as moons? That was a major question raised by a team of researchers who in 2019 collected data that suggested two tremendously massive exomoons are orbiting two distant brown dwarfs.

One of these brown dwarfs has around 10 or 11 times the mass of Jupiter and seems to be orbited by an exomoon around the same mass as the king of the Solar System, while the other brown dwarf has a mass around 13 to 14 times that of Jupiter with an exomoon that's almost five times the gas giant's mass. The planetary system discovered by the team, including University of Padova researcher Cecilia Lazzoni, who presented the results at the fourth Extreme Solar Systems conference in Reykjavik, Iceland, in 2019, is like nothing researchers have ever discovered before. If these potential exomoons can be confirmed, their immense mass means researchers will have to decide if they fit the definition of a moon at all.

Robert Lea
Space science writer
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

Focus on

CHINA BUILDS AN 'ARTIFICIAL MOON' FOR GRAVITY EXPERIMENTS

The new experiment was inspired by a levitating frog

Reported by Ben Turner

Chinese scientists have built an 'artificial Moon' research facility that will enable them to simulate low-gravity environments using magnetism. The facility, launching this year, will use powerful magnetic fields inside a 60-centimetre (23.6-inch) diameter vacuum chamber to make gravity 'disappear'. The scientists were inspired by an earlier experiment that used magnets to levitate a frog. Ruilin Li, a geotechnical engineer at the China University of Mining and Technology, said that the chamber, which will be filled with rocks and dust to imitate the lunar surface, is the "first of its kind in the world" and that it could maintain such low-gravity conditions for "as long as you want."

Scientists plan to use the facility to test technology in prolonged low-gravity environments before it's sent to the Moon, where gravity is just one-sixth of its strength on Earth. This will allow them to iron out any costly technical kinks, test whether certain structures will survive on the Moon's surface and assess the viability of a human settlement there.

"Some experiments, such as an impact test, need just a few seconds [in the simulator]," Li said. "But others, such as creep testing, can take several days." A creep test measures how much a material will deform under a constant temperature and stress.

According to the researchers, the inspiration for the chamber came from Andre Geim, a physicist at the University of Manchester in the UK, who won the satirical Ig Nobel Prize in 2000 for devising an experiment that made a frog float with a magnet. The levitation trick used by Geim – and now in the artificial Moon chamber – comes from an effect called diamagnetic levitation. Atoms are made up of atomic nuclei and tiny electrons that orbit them in little loops of current, and these moving currents induce tiny magnetic fields. Usually, the randomly oriented magnetic fields of all the atoms in an object, whether they belong to a drop of water or a frog, cancel out, and no material-wide magnetism manifests.

Apply an external magnetic field to those atoms, however, and everything changes: the electrons will modify their motion, producing their own magnetic field to oppose the applied field. If the external magnet is strong enough, the magnetic force of repulsion between it and the field of the atoms will grow powerful enough to overcome gravity and levitate the object – whether it's an advanced piece of lunar tech or a confused amphibian – into the air.

The tests completed in the chamber will be used to inform China's lunar exploration program Chang'e, which takes its name from the Chinese goddess of the Moon. This initiative includes Chang'e 4, which landed a rover on the far side of the Moon in 2019, and Chang'e 5, which retrieved rock samples from the Moon's surface in 2020. China has also declared that it will establish a lunar research station on the Moon's south pole by 2029.

"SCIENTISTS PLAN TO USE THE FACILITY TO TEST TECHNOLOGY IN PROLONGED LOW-GRAVITY ENVIRONMENTS BEFORE IT'S SENT TO THE MOON"

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GALAXY PROFILE

THE LARGE MAGELLANIC CLOUD

This nearby dwarf galaxy is a satellite in orbit around our own

The Large Magellanic Cloud (LMC) is a satellite dwarf galaxy of the Milky Way that's among the closest galaxies to Earth. At about 163,000 light years from Earth, the dwarf galaxy looks like a faint cloud in Southern Hemisphere skies. It lies on the border of the constellations Dorado and Mensa.

Both the LMC and its companion, the Small Magellanic Cloud (SMC), are named after the explorer Ferdinand Magellan. While astronomers in the Southern Hemisphere had seen these clouds before Magellan's round-the-world voyage in 1519, the explorer was first to bring that knowledge to the Western world. Magellan died in the Philippines during that voyage, but his crew provided documentation of the discovery upon their return to Europe.

Magellan's discovery of the LMC and SMC predated telescopes, but even after these instruments allowed astronomers in the 17th century to get a closer look, it was still several hundred years before scientists could accurately calculate the distance to the LMC, the SMC and other nearby galaxies. Scientists came to better understand cosmic distances using

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“OTHER THAN ITS PROXIMITY TO EARTH, THE LMC IS ALSO KNOWN FOR BEING A SITE WHERE STARS FORM”

tools such as ‘standard candles’ – objects, such as certain types of variable stars, that have known luminosities. From then on the LMC was considered the closest galactic object to Earth, until 1994, when astronomers found the Sagittarius Dwarf Elliptical Galaxy. Another discovery in 2003, the Canis Major Dwarf Galaxy, turned out to be even closer.

The LMC is part of a collection of dozens of galaxies known as the Local Group, so named because they are fairly close to our Milky Way galaxy. The most prominent member is the Andromeda Galaxy, which lies 2.5 million light years away. Other than its proximity to Earth, the LMC is also known for being a site where stars form. Several observatories have witnessed vast amounts of gas coming together to create young stars within the LMC’s borders.

The LMC is an excellent spot to look if you want to see stars being born. “It lies in a fortuitous location in the sky, far enough from the plane of the Milky Way that it’s neither outshone by too many nearby stars nor obscured by the dust in the Milky Way’s centre,” says NASA. It’s also close enough to study in detail – less than one-tenth the distance to the Andromeda Galaxy, the closest spiral galaxy to us – and lies almost face on to us, giving us a bird’s-eye view. As researchers continue to make more detailed observations of the dwarf galaxies, they hope to learn more about the Milky Way’s enigmatic neighbours. These measurements may help reveal more about our galaxy, too. The LMC carries a significant amount of stars and gas with it as it approaches our galaxy. While that can be helpful, the additional mass makes it more difficult to calculate the movement of other objects whose interactions help scientists determine the Milky Way’s mass.

NEWS FROM THE LARGE MAGELLANIC CLOUD

INCREDIBLE VIEW OF A COSMIC CREEPY-CRAWLY

A 2012 composite image of the Tarantula Nebula – a region of the LMC more properly known as 30 Doradus – revealed violence and radiation through the lenses of the Hubble, Chandra and Spitzer space telescopes. At the centre of the Tarantula Nebula, thousands of massive stars release material and produce radiation, along with powerful winds. The Chandra X-ray Observatory found the gas in the region has been heated to millions of degrees by these stellar winds and supernovae.

In the composite image, the X-rays generated in the star-making region are coloured blue. These X-ray emissions come from shock waves, akin to sonic booms, formed by the high-energy cosmic activity. The red regions represent the infrared emission data collected by Spitzer, highlighting the cooler gas and dust that has been sculpted by the radiation and stellar winds from inside 30 Doradus. If the Tarantula Nebula were as close to Earth as the Orion Nebula – the closest of these stellar nurseries, only 1,344 light years away – it would take up the same area in the sky as 60 full Moons. It would even be bright enough to cast shadows on the ground.

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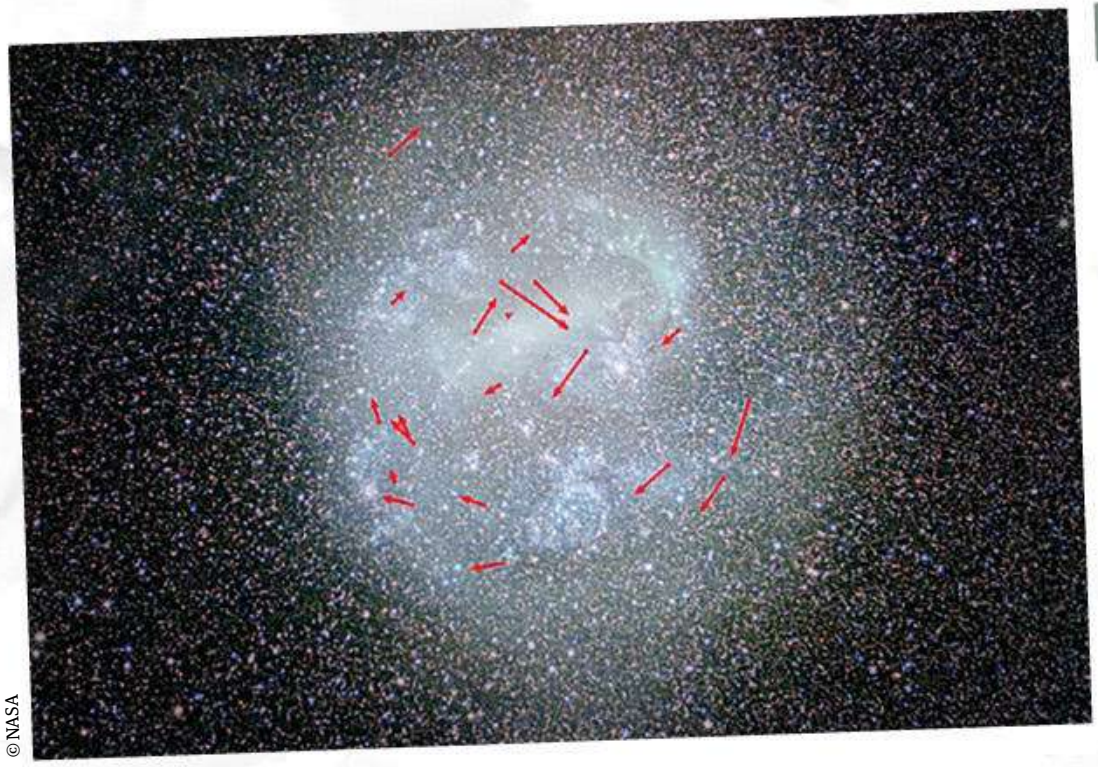

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HUBBLE MEASURES THE ROTATION OF THE LMC

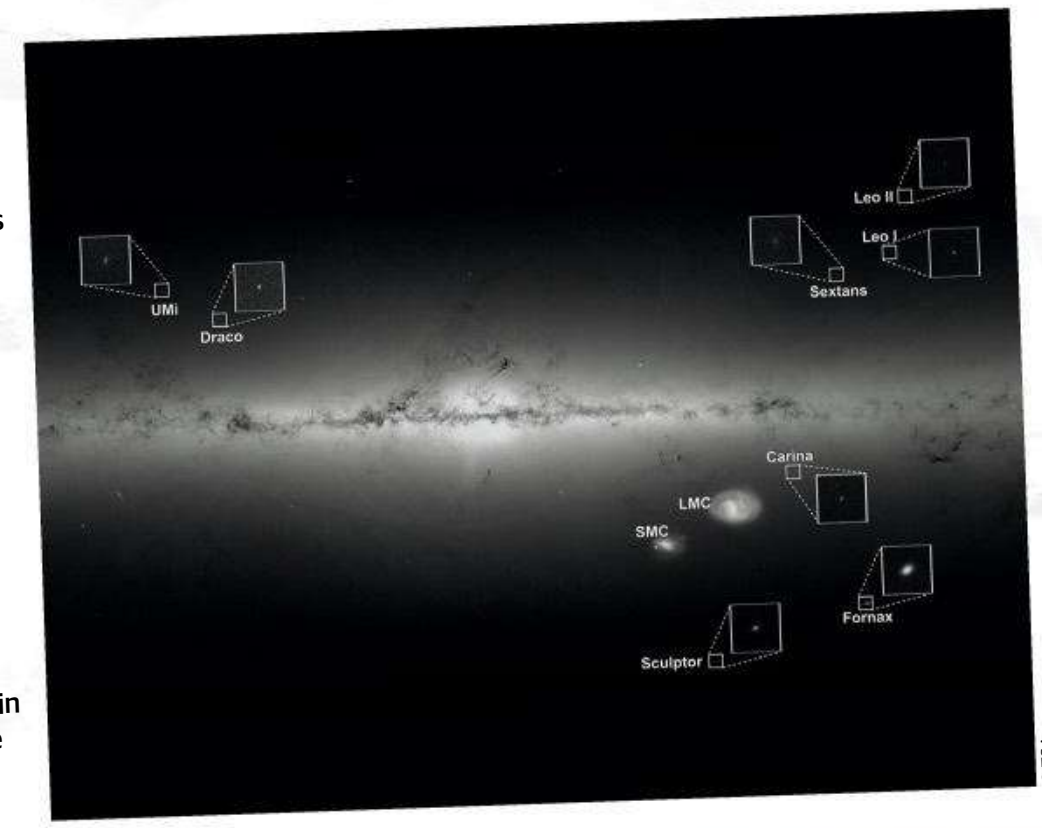
The LMC's relatively close location also affords astronomers the chance to study it in more detail to extrapolate information that can help explain how other galaxies behave. One example is the study of the LMC's rotation, which was picked up by Hubble and published in February 2014. "Studying this nearby galaxy by tracking the stars' movements gives us a better understanding of the internal structure of disc galaxies," Nitya Kallivayalil, a researcher at the University of Virginia, said. "Knowing a galaxy's rotation rate offers insight into how a galaxy formed, and it can be used to calculate its mass."

Researchers discovered that the LMC makes a rotation every 250 million years. They found this by using Hubble to track the motion of stars in the galaxy sideways with respect to the plane of the sky. While this technique has been used for other nearby objects before, this effort represented the first time the method was used for a galaxy. The team plans to turn its attention to the SMC to do the same sort of analysis. Since the SMC and the LMC are also close enough to gravitationally interact with each other, looking at how they move in relation to one other may reveal information about the movements of other galaxies in the Local Group.

NEWCOMERS TO THE MILKY WAY

The LMC and SMC were originally thought to have made multiple trips around the Milky Way. Scientists said the gravitational pull of the Milky Way is what caused the tail of gas and dust known as the Magellanic Stream, which was ripped from the SMC. However, in the 2000s scientists realised that the pair of clouds are making their very first trip around the Milky Way. By pointing Hubble towards the two clouds, scientists began to catch a glimpse of the objects' histories. "They're moving too fast to have been long-term companions of the Milky Way," said Gurtina Besla, a researcher at the University of Arizona who studies dwarf galaxies.

The LMC and SMC are not alone. In November 2021, scientists calculated the movements of 40 dwarf galaxies around the Milky Way using data from the European Space Agency's Gaia spacecraft. The dwarf galaxies had been widely believed to surround the Milky Way as satellites, having been caught in orbit around our galaxy. However, scientists have found that these galaxies are moving a lot faster than star clusters and giant stars known to be orbiting the Milky Way. Interactions with our galactic home reduce orbital energy and angular momentum. Scientists believe that the speedy dwarf galaxies must have only arrived in the vicinity of the Milky Way in the last billion years. While some of these dwarf galaxies will eventually be captured by the Milky Way, some will simply pass by and become satellites.



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LARGE VS SMALL MAGELLANIC CLOUD

	LMC	SMC
TYPE	Disrupted barred spiral	Dwarf irregular galaxy
DIAMETER	14,000 light years	7,000 light years
DISTANCE FROM EARTH	158,200 light years	199,000 light years
NUMBER OF STARS	30 billion	3 billion
CONSTELLATION	Dorado and Mensa	Tucana and Hydrus
GROUP	Local Group	Local Group

"THE LMC WILL APPEAR AS A HAZY SMUDGE IN THE SKY, AND IF IT'S DARK ENOUGH IT CAN EVEN BE SEEN WITH THE UNAIDED EYE"

HOW TO SEE THE LARGE MAGELLANIC CLOUD

The Large Magellanic Cloud can be found on the border of the constellations Dorado and Mensa. To find the LMC, first find Sirius, then follow a line past the right side of Canopus. The LMC will appear as a hazy smudge in the sky, and if it's dark enough it can even be seen with the unaided eye. The LMC and SMC are most easily viewed from the Southern hemisphere.

Magnitude: +0.9
Apparent size: 10.75° by 9.17°
Right ascension: 05h 23m 34.5s
Declination: −69° 45′ 22″
Constellation: Dorado and Mensa

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LARGE MAGELLANIC CLOUD TIMELINE

- **Date:** 5 to 12 billion years ago
  Activity: This quiet period of activity in the LMC is known as the quiescent epoch.
- **Date:** 5 billion years ago
  Activity: The resumption of rapid star formation; half of the LMC's stellar mass was assembled during this time. Star formation has continued ever since.
- **Date:** 2 billion years ago
  Activity: Enhanced star formation in the centre of the LMC.
- **Date:** 500 million years ago
  Activity: Period of rapid star formation.
- **Date:** 100 million years ago
  Activity: Episode of increased star formation along the present-day bar.
- **Date:** 12 million years ago
  Activity: The Milky Way disc began to grow, and the outer regions of the disc formed.
- **Date:** 2 million years ago
  Activity: Formation of 30 Doradus, also known as the Tarantula Nebula.

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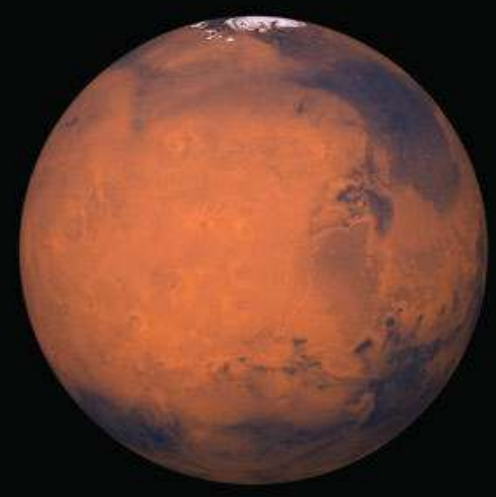
Above: A VISTA survey view of the Tarantula Nebula in the LMC

Right: The Large and Small Magellanic Clouds can be seen as bright smudges in the sky at the centre of this photograph of ALMA's antennae

COLD, DAMP MARS MAY HAVE HOSTED AN ANCIENT OCEAN



Northern parts of the Red Planet could have supported bodies of liquid 3 billion years ago

Reported by Charles Q. Choi

New 3D climate simulations of the planet's ancient atmosphere and water suggest a liquid ocean once existed in the northern lowland basin of Mars. This ocean may have persisted even when average global surface temperatures were below freezing. Although present-day Mars is cold and dry, decades of evidence suggests the ancient surface was covered with rivers, streams and lakes. Since water on Earth usually points to life, these old signs of water raise the possibility that the Red Planet was once home to life.

Earth and Mars likely had similar climates about 3 billion years ago, when life was spreading on our planet. However, scientists debate whether Mars was temperate enough to host an ocean of water. NASA's Perseverance rover is one of many missions sent to Mars to assess the planet's suitability for hosting ancient water.

The new findings contradict previous research suggesting Mars couldn't support such an ocean 3 billion years ago. Relatively few branching river valleys date to that time on Mars, suggesting a lack of intense and widespread rainfall expected from a warm and wet climate. But not all evidence points to a dry world; other evidence of contemporary tsunami debris argues against a Martian climate that was too cold and dry for an ocean. The new study suggests a liquid northern ocean was possible because ocean circulation patterns may have warmed up the surface of that region up to 4.5 degrees Celsius (40.1 degrees Fahrenheit), well above water's freezing point.

More water was possibly in ample supply, too. The northern ocean could have experienced moderate rainfall within it, as well as near its shorelines. Another potential source was flowing glaciers from the southern highlands of the Red Planet, which hosted ice sheets.

An ocean-friendly Martian atmosphere looks somewhat like the carbon dioxide-filled version we see today, but with a twist: roughly ten per cent of the atmosphere was made up of ten per cent hydrogen gas, potentially being released by volcanoes, cosmic impacts or chemical interactions between water and rock. Today, by contrast, hydrogen is only present in trace amounts. This combination of carbon dioxide and hydrogen could have trapped enough heat from the Sun to keep surface temperatures warm enough for an ocean of liquid water.

It remains uncertain, however, whether this ocean could have supported life. "We are only studying the conditions where life could appear," study lead author Frédéric Schmidt, a planetary scientist at the University of Paris-Saclay, said. "A large standing body of water stable for a long time is important, probably necessary, but maybe not sufficient for life to appear." Scientists are also unsure where the water went, Schmidt noted. Much of it could be frozen as ice under the surface of Mars, or chemically locked away in minerals. Solar radiation may have also broken water molecules apart into hydrogen and oxygen gases, with the hydrogen gas ultimately escaping into space, he added. NASA is currently tracking present-day Red Planet gas emissions through missions such as MAVEN (Mars Atmosphere and Volatile Evolution).

In the future, China's Zhurong rover – along with the planned ExoMars Rosalind Franklin rover from the European Space Agency and Russia's Roscosmos – could analyse the proposed boundary of this ancient ocean to confirm whether there are a shoreline and tsunami deposits there, the scientists said. In the longer term, the proposed International-Mars Ice Mapper mission could uncover additional signs of ancient seas on Mars. Future research may also explore what exact paths glaciers took to reach this ocean to assist scientists in mapping geological evidence of glacial routes. "For the moment, our simulation cannot predict that," Schmidt said.

"THE NORTHERN OCEAN COULD HAVE EXPERIENCED MODERATE RAINFALL WITHIN IT"

© Getty

Above: The Red Planet today is a dry and desolate desert world

EVERYTHING YOU NEED TO KNOW ABOUT SATURN

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WITH ITS MOON SYSTEM, RINGS OF DUST AND ICE AND OCCASIONALLY TEMPESTUOUS ATMOSPHERE, THERE'S MORE TO THIS GAS GIANT THAN MEETS THE EYE

Written by Giles Sparrow

Saturn is our Solar System's ringed wonder – a spectacular world encircled by planes of icy debris, giving it a unique appearance. But there's a lot more to Saturn than just its rings; this enormous world is worth exploring both for its own complexity and the fascinating family of satellites that orbit it. As the most distant Solar System object easily seen with the naked eye, Saturn orbits at an average of 1.43 billion kilometres (887 million miles) from the Sun. Its slow orbit means that Saturn takes 29.5 years to make a full circuit through the constellations of the zodiac; it was this stately movement that led ancient stargazers to associate it with the father of Jupiter in Roman mythology.

Its distance makes it a challenging object for study, even in the era of giant telescopes. Most of what we know about the planet comes from the Voyager probe flybys in the 1980s and the Cassini mission that orbited between 2004 and 2017. Earth observations, coupled with close-up images from these explorers, have revealed that what often appears to be a placid orb of creamy cloud is in fact a surprisingly active world.

SATURN'S MOONS

DAPHNIS

Dimensions: 8.6 by 8.2 by 6.4 kilometres (5.3 by 5.1 by 4.0 miles)

Mass: 0.08 x 10^{12} tonnes

Orbital period: 0.59 days

Discovered: Cassini, 2005

MIMAS

Diameter: 396 kilometres (246 miles)

Mass: 37.4 x 10^{15} tonnes

Orbital period: 0.94 days

Discovered: William Herschel, 1789

ENCELADUS

Diameter: 504 kilometres (313 miles)

Mass: 108.0 x 10^{15} tonnes

Orbital period: 1.37 days

Discovered: William Herschel, 1789

TETHYS

Diameter: 1,062 kilometres (659 miles)

Mass: 617.4 x 10^{15} tonnes

Orbital period: 1.89 days

Discovered: Giovanni Domenico Cassini, 1684

DIONE

Diameter: 1,123 kilometres (698 miles)

Mass: 1095.4 x 10^{15} tonnes

Orbital period: 2.74 days

Discovered: Giovanni Domenico Cassini, 1684

Internally, Saturn is a gas giant like Jupiter, a huge ball dominated by the lightweight elements hydrogen and helium. It owes its very different outward appearance to a substantially lower mass – Saturn weighs as much as 95 Earths, but this is less than a third of Jupiter. The weaker gravity allows Saturn's upper layers to billow outwards, giving it the lowest average density of any world in the Solar System – about two-thirds that of water.

Combined with a rotation period of just ten-and-a-half hours, Saturn struggles to hold onto material around its fast-moving equator, giving the planet a pronounced bulge around the middle. At 120,532 kilometres (74,895 miles), Saturn's equatorial diameter is almost 12,000 kilometres (7,456 miles) more than its polar diameter. The planet's low density also means its atmosphere is cooler, and combined with its distance from the Sun means that temperatures in the uppermost layers plunge to a chilly -176 degrees Celsius (-285 degrees Fahrenheit). This creates conditions where ammonia can condense into ice crystals and form hazy white clouds that blanket the planet, muting the colours and detail of features deeper inside the atmosphere. Visiting space probes have confirmed a wide range of atmospheric compounds, including ethane, methane and ammonia, while the deeper clouds likely consist of ammonium hydrosulfide or water. Differences in the cocktail of chemicals are probably mostly responsible for Saturn's restrained palette in comparison with Jupiter.

Despite its relatively monotone appearance, Saturn's atmosphere is far from dormant. Space probes have recorded wind speeds of up to 1,800 kilometres (1,118 miles) per hour, the second fastest in the Solar System after Neptune, forming jet streams that wrap around the planet. Saturn's major cloud bands run parallel to the equator; they are broader and fewer in number than those around Jupiter, but still give rise to intense storms that appear as bright ovals and persist for weeks.

Although Saturn has no permanently visible storms to match Jupiter's Great Red Spot, it intermittently produces seasonal storms on just as grand a scale. The most famous, known as the Great White Spot, erupted in the northern hemisphere at roughly 30-year intervals from 1876 until 1990. Its regular cycle suggests a link to seasonal changes in the upper atmosphere. With its equator tipped at an angle of 26.7 degrees to its orbit, Saturn goes through an Earthlike pattern of seasons each long year. But the spot's unexpected early reappearance in 2010 – and absence since – suggest things may be more complicated.

Beneath its outer cloud layers, Saturn's internal structure is governed by the increasing temperature and atmospheric pressure deeper inside the planet. About 1,000 kilometres (621 miles) below the visible surface, its hydrogen gas is so compressed that it condenses into liquid. Some way below this, conditions become so extreme that hydrogen molecules are broken apart, forming a sea of electrically charged liquid metallic hydrogen that generates a powerful magnetic field as the planet spins. The exact structure of Saturn's core remains something of a mystery, but recent studies of the way it affects the planet's rings suggests it is probably fuzzy or diffuse, amounting to about 17 Earth masses of material and extending 60 per cent of the way to the surface, where it becomes mixed with the metallic hydrogen above. Deep within the planet, one or more mechanisms generate vast amounts of heat, allowing Saturn to radiate 2.5 times more energy than it receives from the Sun. In part this is probably due to a well-understood mechanism of gravitational contraction that sifts denser material towards the core, but it's

Left: Taken as Cassini passed through Saturn's shadow, this spectacular image reveals the planet and its ring system backlit by the Sun

© NASA/JPL-Caltech

RHEA

Diameter: 1,528 kilometres (949 miles)

Mass: 2306.5 x 10^{15} tonnes

Orbital period: 4.52 days

Discovered: Giovanni Domenico Cassini, 1672

TITAN

Diameter: 5,149 kilometres (3,199 miles)

Mass: 134,520.0 x 10^{15} tonnes

Orbital period: 15.95 days

Discovered: Christiaan Huygens, 1655

HYPERION

Dimensions: 360 by 266 by 205 kilometres (223 by 165 by 127 miles)

Mass: 5.6 x 10^{15} tonnes

Orbital period: 21.28 days

Discovered: William Cranch Bond, William Lassell, 1848

IAPETUS

Diameter: 1,469 kilometres (913 miles)

Mass: 1805.6 x 10^{15} tonnes

Orbital period: 79.32 days

Discovered: Giovanni Domenico Cassini, 1671

PHOEBE

Dimensions: 219 by 217 by 204 kilometres (136 by 134 by 127 miles)

Mass: 8.3 x 10^{15} tonnes

Orbital period: 550 days

Discovered: William Henry Pickering, 1899

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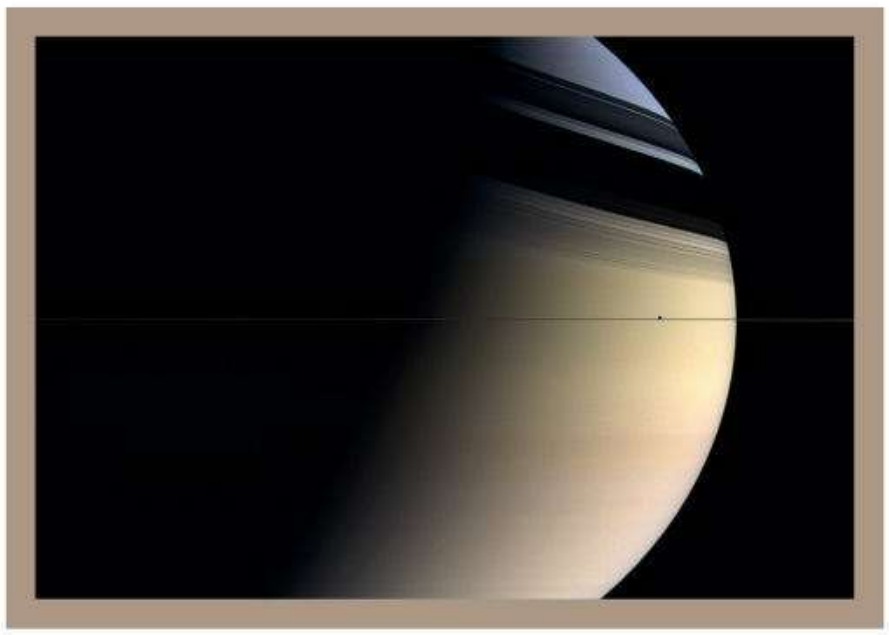

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Above: Saturn's razor-thin rings cast huge shadows across the planet in this image, captured as Cassini's orbit aligned with the plane of the rings in 2006

likely that other chemical and physical processes within the liquid layers also play a role.

Although all four of the Solar System's giant planets are now known to have rings of one kind or another, Saturn's are by far the brightest and most extensive. They were first spotted by Galileo Galilei in 1610, though his crude telescope could only show that the planet appeared strangely elongated. It wasn't until 1659 that Christiaan Huygens realised the true structure of the rings as a broad but thin disc around the planet, which disappears from view when the plane of the rings lines up with Earth twice in each Saturnian year.

The two brightest rings, stretching to about 2.4 times Saturn's diameter, are designated A and B, and are separated by a mostly empty gap, the Cassini Division. Inward of the B Ring lies the C Ring, semi-transparent but still visible from Earth, while a tenuous D Ring extends all the way down to Saturn's upper atmosphere. The narrow braid of the F Ring hems the A Ring's outer edge, while several minor rings – fragmentary 'arcs' or clouds of tiny particles – lie still further out.

The laws of physics mean that it's impossible for rings to be solid bodies – the varying strength of Saturn's gravity would tear them apart. Instead, each ring – and the many distinct ringlets within them – is composed of countless icy fragments,

"THE EXACT STRUCTURE OF SATURN'S CORE REMAINS SOMETHING OF A MYSTERY"

INSIDE SATURN

1 AMMONIA HAZE

Cold conditions in the upper atmosphere allow ammonia to condense and form bright, hazy clouds at pressures between roughly 0.4 and 1.7 times Earth's atmospheric pressure.

2 DEEPER CLOUDS

As pressure increases further into Saturn's atmosphere, other chemicals condense into droplets and form clouds – in particular ammonium hydrosulfide and a water ice/ammonia mix.

3 LIQUEFIED GAS

At a depth of about 1,000 kilometres (621 miles), pressures reach 1,000 Earth atmospheres – enough for hydrogen to condense into its liquid molecular form.

4 METALLIC OCEAN

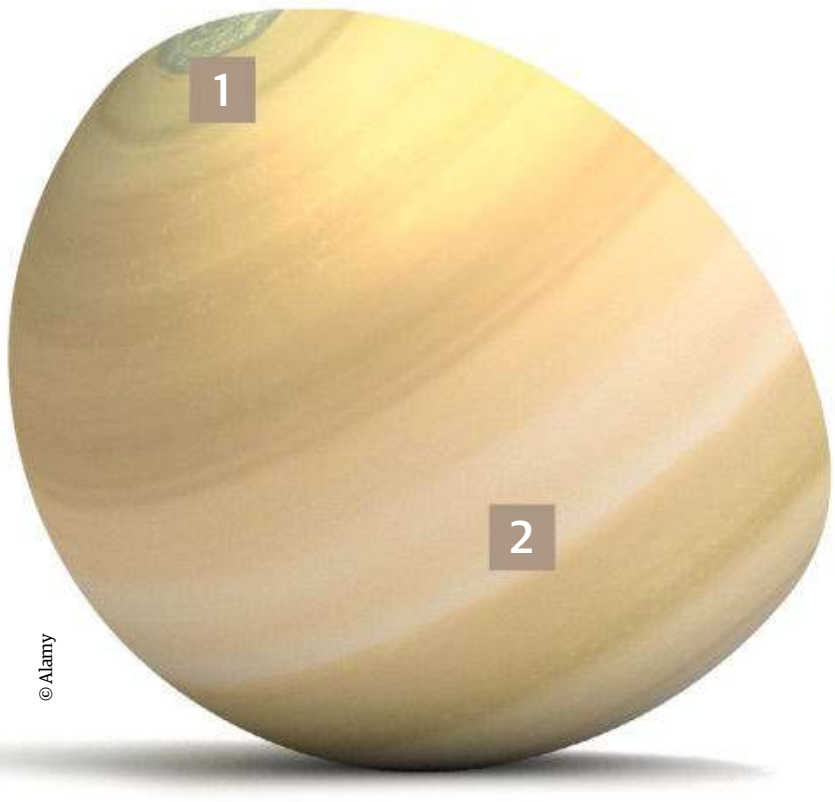
Here pressures reach 2 million Earth atmospheres and temperatures rival the surface of the Sun. Hydrogen molecules split apart to form a sea of electrically charged metallic hydrogen.

5 FUZZY CORE

Recent studies suggest Saturn has a fuzzy core that begins where heavy elements mix with the liquid metallic layer, and it grows denser towards the centre.

6 SOLID CENTRE?

The scientific jury is still out on whether Saturn has a distinct solid core of rock and metal.



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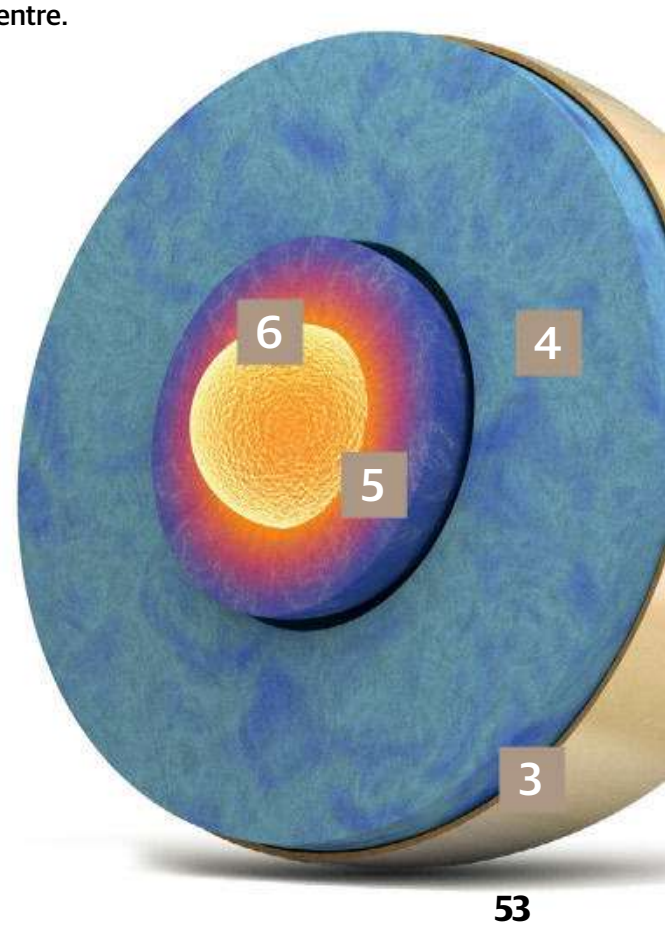

SATURN

MAJOR MISSIONS TO SATURN

PIONEER 11

Type: Jupiter and Saturn flyby

Launched: 5 April 1973

Saturn flyby: 1 September 1979

Key discoveries: First close-up images of Saturn. Measurements of the magnetic field. Measured the temperature of Titan and photographed the unlit underside of the rings

Status: Contact lost; now entering interstellar space

VOYAGER 1

Type: Jupiter and Saturn flyby

Launched: 5 September 1977

Saturn flyby: 12 November 1980

Key discoveries: Analysis of Saturn's upper atmosphere. Discovery of complex structure in the rings of Saturn. Close-up images of Titan and other Saturnian moons

Status: Entered interstellar space in 2012; still returning data about its conditions to Earth

VOYAGER 2

Type: Multi-planet flyby

Launched: 20 August 1977

Saturn flyby: 26 August 1981

Key discoveries: Measurement of temperature in the upper atmosphere. Images of more structure in the rings and the first close-up views of moons including Enceladus

Status: Entered interstellar space in 2018; still returning data to Earth

CASSINI

Type: Saturn orbiter

Launched: 15 October 1997

Saturn orbit: 1 July 2004

Key discoveries: Detailed survey of Saturn, its rings and moons. Monitored Great White Spot outbreak of 2010. Imaged Titan through its clouds and discovered water plumes above Enceladus.

Status: Destroyed during a controlled plunge into Saturn's atmosphere on 15 September 2017 to protect moons from possible contamination.

HUYGENS

Type: Titan lander

Launched: 15 October 1997

Titan descent: 14 January 2005

Key discoveries: First descent through Titan's atmosphere and images from the surface. Landed in a dry river delta amid pebbles of water ice

Status: Contact with Cassini lost 72 minutes after landing

DRAGONFLY

Type: Planned Titan lander

Launch: 2027

Titan landing: 2034

Key goals: Dragonfly is a helicopter-like robotic explorer designed to fly across Titan's surface and visit several locations, studying the moon's complex surface chemistry and potential for life.

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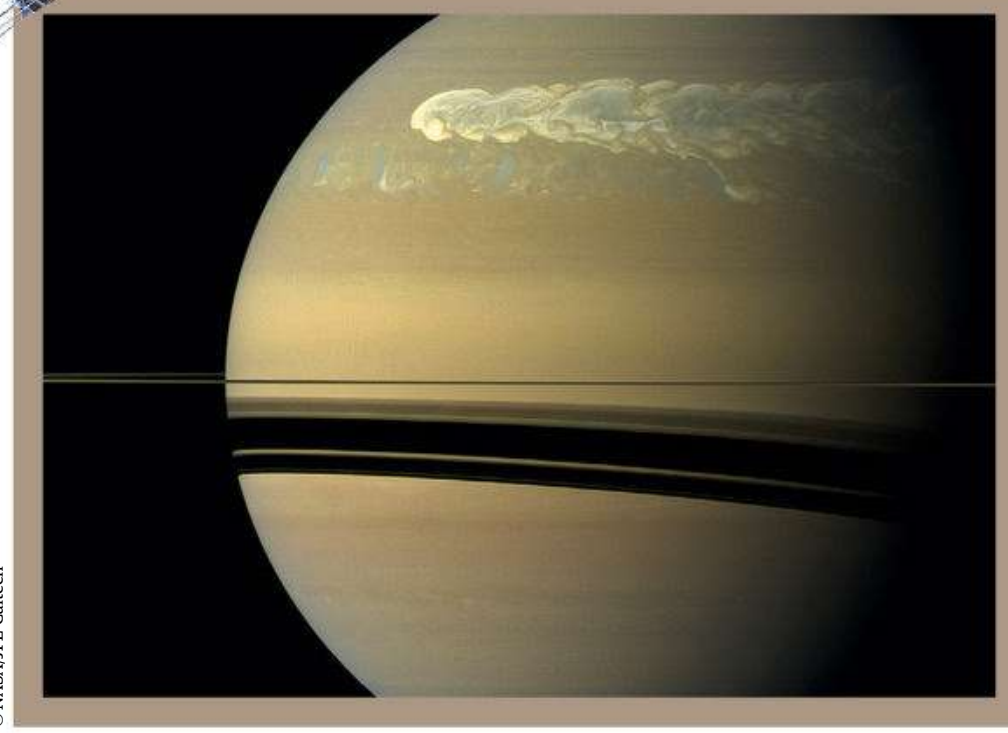

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Above: After reappearing in late 2010, Saturn's Great White Spot soon developed a tail that wrapped around the planet as it became distorted by high winds

Right (top): Cassini captured long shadows cast by ragged material at the outer edge of the B Ring as the Sun rose over the southern face of the rings shortly after Saturn's 2009 equinox

Right: Sunlight scattered through the rings casts a blue wash across Saturn's northern hemisphere, providing a stunning backdrop to this view of the innermost large moon Mimas

each following its own individual orbit around the planet. The orbits are almost perfectly circular and lie in a single narrow plane less than a kilometre (0.62 miles) deep, but the system is constantly evolving as the gravity of Saturn's major moons pulls fragments out of this neat arrangement and collisions with their neighbours jostle them back into line. Cassini images have revealed increasing levels of detail within the rings, including dark radial 'spokes' rippling their way across the rings like a wave and propeller-shaped structures caused by ring fragments clumping together.

Within and just beyond the rings, probes have traced the influence of so-called 'shepherd moons' such as Daphnis – small satellites ranging from a few kilometres to a few tens of kilometres across that keep individual ringlets in line, create gaps in the system and may even contribute fresh material to the rings. The evolving nature of the system, which grinds down ring fragments over time and ultimately loses material as it spirals down onto Saturn's equator, means that the rings must either be relatively young – one recent analysis points to formation from the breakup of a large, icy comet about 100 million years ago – or have somehow been replenished with new material over time.

The shepherd moons are just the innermost members of a vast family; with 82 members at the most recent count, Saturn has the biggest satellite system of any of the major planets. Beyond the rings orbit eight major moons, substantial worlds that formed from material left behind during the birth of Saturn itself. The inner five major moons follow a broad trend of increasing size, from 400-kilometre (248-mile) Mimas, through Enceladus, Tethys and Dione, to 1,500-kilometre (932-mile) Rhea; each consists of a mix of ice and rock, and most show signs of geological activity at various stages in their past, most likely low-temperature cryovolcanism creating eruptions of icy slush. The exception is the extraordinary Enceladus – a brilliant-white world 504 kilometres (313 miles) in diameter whose terrain has not only

TOP 5 DISCOVERIES

1 THE DRAGON STORM

Usually hidden deep beneath the clouds, this long-lived storm occasionally sends plumes of white cloud to the surface and goes through periods of violent lightning activity.

2 POLAR HEXAGON

Saturn's north pole is home to a giant hexagonal cloud structure 30,000 kilometres (18,641 miles) across. At its very centre lies a swirling vortex-like feature that's matched by one at the south pole.

3 RING RIPPLES

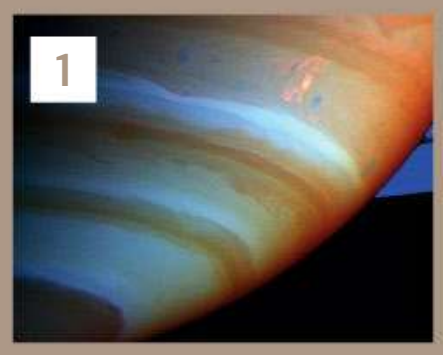
Saturn's rings are constantly reshaped by the gravitational influence of its moons – here the 86-kilometre (53-mile) Prometheus creates dark channels in the narrow F Ring as it disrupts the orbits of individual ring fragments.

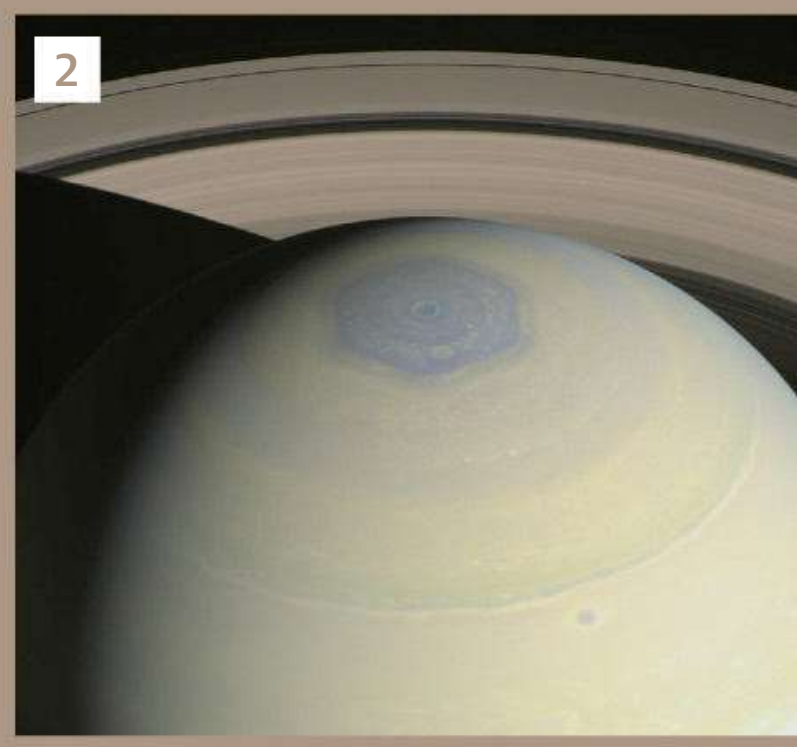
4 PLUMES OF ENCELADUS

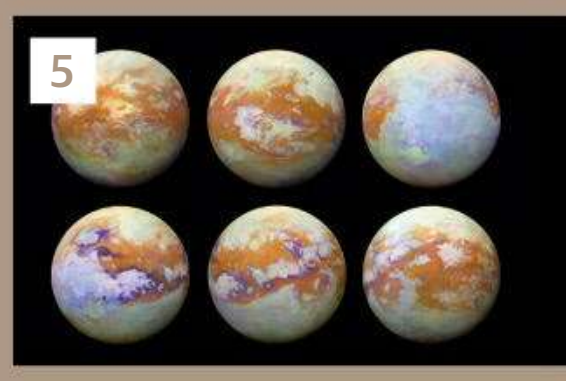
Jets of water vapour erupt from seas just beneath the icy crust of Enceladus, spraying snow across the surface and forming the doughnut-shaped E Ring that surrounds the moon's orbit.

5 TITAN'S EERIE GEOGRAPHY

Infrared images have revealed that Titan is a complex world with a fresh, mostly uncratered terrain.







x5 Images © NASA/JPL-Caltech

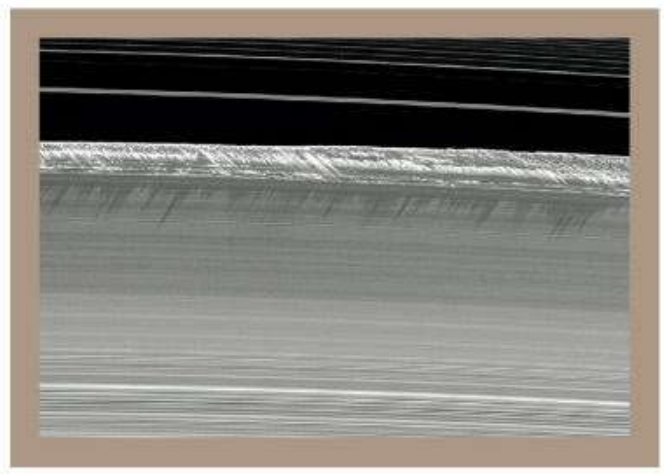
been reshaped by very recent resurfacing, but is also blanketed in fresh snow. Heat generated as Enceladus is distorted by a gravitational tug of war between Saturn and its outer neighbouring satellites warms the moon's south polar region, creating reservoirs of liquid water just beneath the icy crust. As the surface flexes, water escapes into space, shooting huge plumes of vapour high above the moon's surface. Enceladus' near-surface liquid water makes it a prime candidate in the search for life elsewhere in the Solar System.

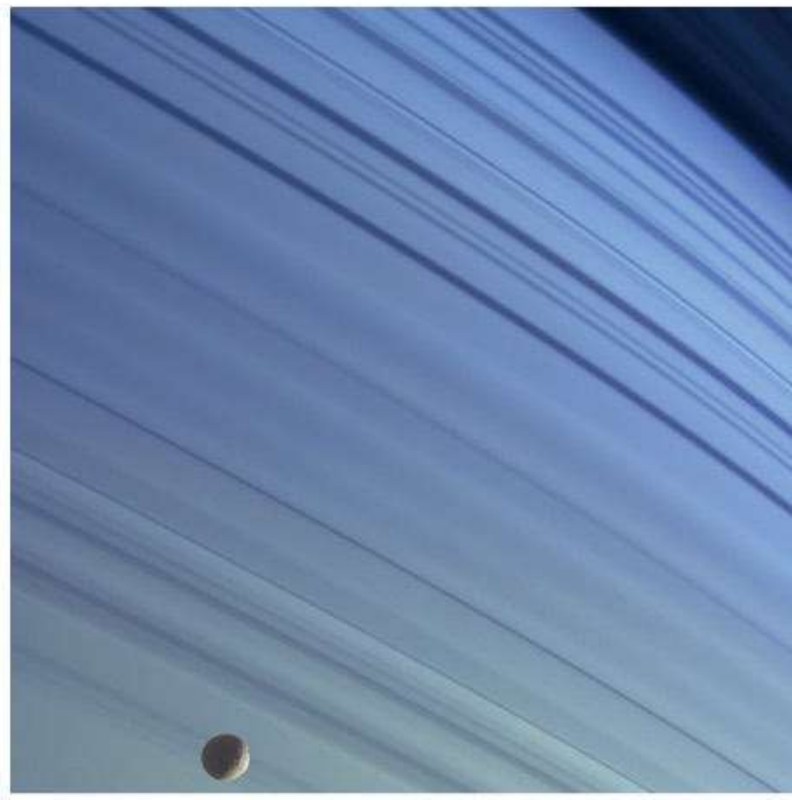
The centrepiece of Saturn's moon system, the appropriately named Titan, dwarfs all the other satellites. With a diameter of 5,149 kilometres (3,199 miles), it's the second-largest moon in the entire Solar System after Jupiter's Ganymede. A combination of high gravity and cold conditions allow Titan to hold onto a substantial atmosphere, making it one of a kind among Solar System satellites. This atmosphere is mostly nitrogen, but a small amount of methane forms clouds that render it an opaque orange. When the Cassini probe's infrared cameras pierced this veil, they revealed a curiously Earthlike landscape with eroded 'continents' and low-lying plains that resemble ocean basins. With an average temperature of -179 degrees Celsius (-111 degrees Fahrenheit), Titan's terrain has been shaped by both cryovolcanic activity and a 'methane cycle' resembling Earth's water cycle, This involves the volatile chemical shifting between atmospheric gas, solid ice and liquid rain that erodes the surface and gathers in lakes around the moon's winter pole.

The final two large moons are also intriguing. Spongelike and misshapen Hyperion is a mere 360 kilometres (223 miles) long, and is thought to be a surviving fragment of a moon that was once much larger. Iapetus, which rivals Rhea in size, has starkly contrasting light and dark hemispheres, the end result of a complex process that begins with Iapetus picking up dust that spirals Saturnwards from its dark outer neighbour Phoebe.

Phoebe itself is the largest of more than 50 outer 'irregular' moons – small icy bodies that follow tilted, elongated and sometimes backward orbits. Grouped into several distinct families, they are thought to be the fragmented remains of comets or asteroids from the outer Solar System, captured by Saturn's gravity long after their formation. Together, the outer limits of their distant orbits extend the limits of this dazzling system to more than 30 million kilometres (18.6 million miles) from Saturn itself.

Giles Sparrow
Space science writer
Giles has degrees in astronomy and science communication and has written many books and articles on all aspects of the universe.





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WHAT DRIVES JUPITER'S POLAR CYCLONES?

The Juno spacecraft has solved the mystery of storm dynamics on the gas giant

Reported by Tereza Pultarova

Giant cyclones around the poles of the Solar System's largest planet are generated by the same forces that move water in Earth's oceans. Jupiter's gargantuan polar cyclones, which are up to 1,000 kilometres (620 miles) across, were first spotted in 2016 by NASA's Juno probe. Since then, scientists have speculated that these storms are driven by convection, the process known from Earth in which hotter air expands and rises to higher, colder and denser altitudes. Until now, however, they couldn't prove the existence of this process on Jupiter.

Oceanographer Lia Siegelman, a postdoctoral researcher at Scripps Institution of Oceanography at the University of California, San Diego, realised that those polar cyclones looked strikingly similar to ocean vortices that scientists study on our planet. "When I saw the richness of the turbulence around the Jovian cyclones, with all the filaments and smaller eddies, it reminded me of the turbulence you see in the ocean around eddies," said Siegelman. "These are especially evident on high-resolution satellite images of plankton blooms, for example."

Siegelman and her colleagues analysed a series of images of the cyclones surrounding Jupiter's north pole captured in infrared wavelengths, those that reveal the heat emitted by an object. The researchers used the same methodology that helps scientists study large-scale flows of air and water in Earth's atmosphere and oceans.

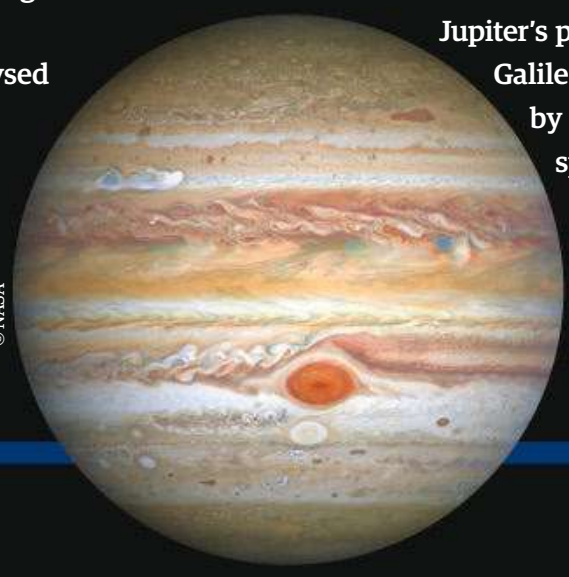
This enabled them to calculate the direction and speed of local winds and to track the movement of clouds. The researchers were able to distinguish areas with thin cloud cover, where they could see deeper into Jupiter's atmosphere, and those obscured by a thick blanket of fog. The analysis proved that rising hot air transports energy within the atmosphere and feeds the clouds as they grow into large-scale cyclones, such as those observed around the poles.

"To be able to study a planet that is so far away and find physics that apply there is fascinating," said Siegelman. She added that just as the science of Earth's oceans is now helping to unlock the mysteries of Jupiter's atmosphere, the new findings could in turn help shed new light on those large-scale processes on Earth. For example, the physical mechanism at play on Jupiter could reveal routes of energy exchange that could also exist on our planet and scientists have not yet identified.

Juno is the first spacecraft to photograph Jupiter's poles. Previous probes, like the 1989 Galileo mission, explored the giant planet by orbiting along its equator. The Juno spacecraft found eight cyclones around the planet's north pole and five in the south, all of which are still present and churning more than five years after their discovery.

Right: Artist's impression of turbulent Jovian storms

Below: Jupiter is made up of horizontally rotating cloud bands



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"TO BE ABLE TO STUDY A PLANET THAT IS SO FAR AWAY AND FIND PHYSICS THAT APPLY THERE IS FASCINATING"

LIA SIEGELMAN

MYSTERIES OF THE UNIVERSE

WHAT DISTURBED A DISTANT STAR SYSTEM?

Astronomers are a step closer to understanding how our Solar System formed, all thanks to a chance encounter

Reported by David Crookes

One of the greatest mysteries that astronomers hope to one day solve is how our Solar System formed. It's long been known that star systems are shaped by collisions and other disruptive events, so whenever scientists are lucky enough to directly observe such an occurrence, it takes researchers one step closer to the answer.

In 2021, scientists made a breakthrough. They used the Atacama Large Millimeter/submillimeter Array (ALMA), along with the Karl G. Jansky Very Large Array (VLA), to peer at the Z Canis Majoris (Z CMa) star system. They wanted to study a stream of dust and gas that was stretching far into the darkness of space. In doing so they happened to capture an object which they could see had smashed into the protoplanetary disc of leftover material surrounding the protostar pair, and it got them very excited indeed.

Z CANIS MAJORIS STAR SYSTEM BY NUMBERS

300,000
years old

THREE
Probable number of stars – the two in the central binary plus the flyby, likely also a star

100
Distance between the stars in astronomical units

3,750
Light years from Earth

2,000
Length of the streamer in astronomical units

4,700
AU to the flyby object that disrupted Z CMa

2021
Year the object was discovered

TWO
Sets of telescopes used to find the object

ONE
telescope saw the streamer but not the object

Below: Here you can see the different observations of the object that entered the Z CMa system. The scattered-light observations are shown in the top right. The other images show dust continuum emissions and the 13CO line

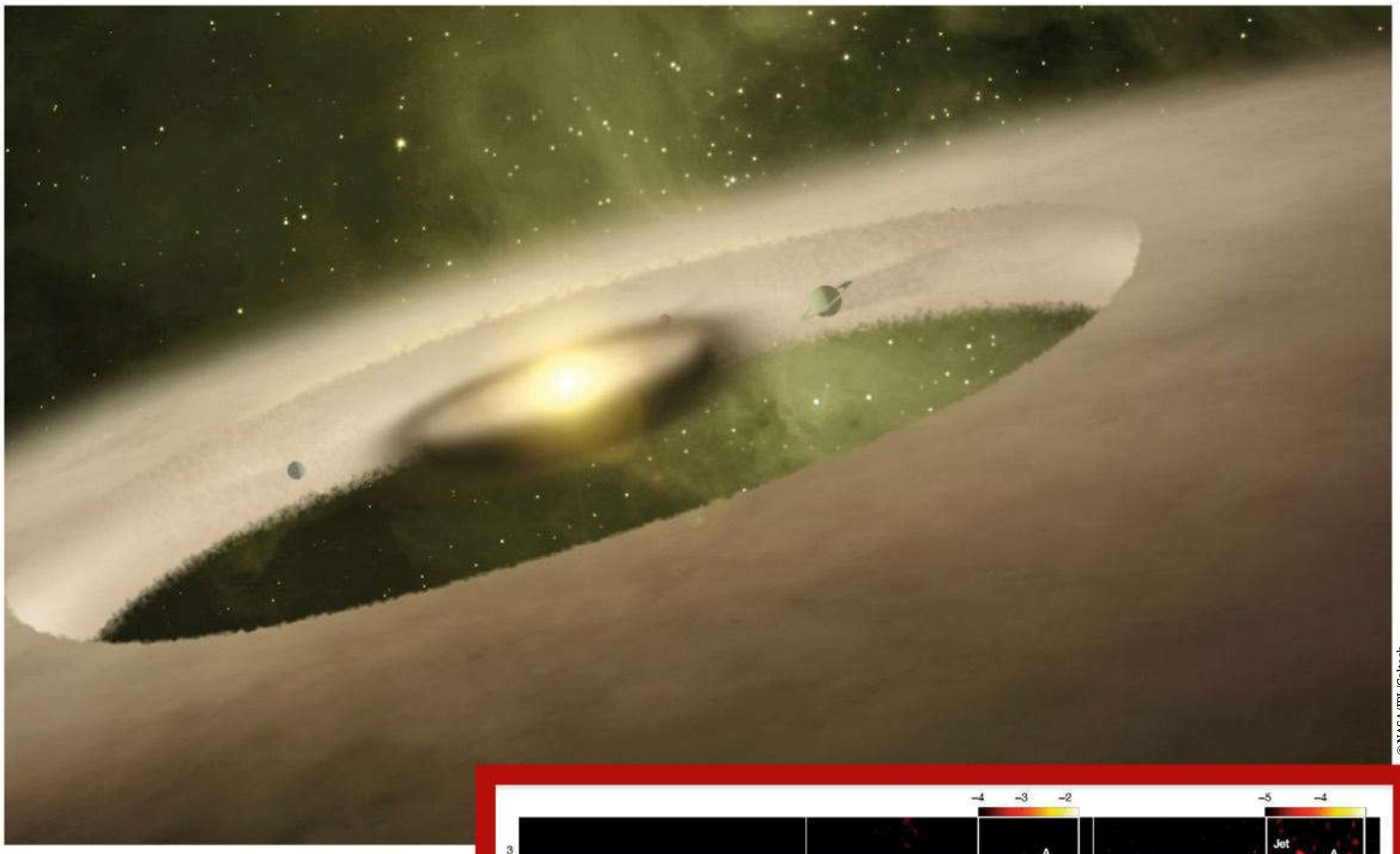
Although astronomers had previously observed the effects of the collision – the streamer, as it's referred to – this time researchers found something else. "We detected it almost purely by chance," says Ruobing Dong, an astronomer at the University of Victoria in Canada and principal investigator of the study. "It was like going on a hiking trip, finding a beautiful leaf on a tree and taking a photo of it, only to examine the photo afterwards and find lightning in the background sky."

What they saw was the object that appeared to have caused the collision – something that wasn't even bound to the Z CMa star system and instead came from elsewhere. The intruder had flown past, collided with and smashed a chunk of the protoplanetary disc away. The discovery may have been sheer luck, but it was nevertheless a chance observation that would prove to be of great importance. "We'd pointed ALMA and the VLA to Z CMa at the time to study its streamer, and the flyby object just showed up in the photo. It was kind of a surprise."

Up until this point, flyby events involving an intruder had been largely theoretical. "They're largely theoretical because flyby events occur on a very short timescale and they are hard to capture in observations," Dong explains. Instead, astronomers based their beliefs on predictions made over and over again by numerous computer simulations. "Here's an analogy," Dong continues. "It's easy to do computer simulations of lightning events, but it's hard to take a photo of one in the real world. But computer simulations are robust, and the physics in simulating a flyby event is nothing fancy. It's just what Newton found hundreds of years ago, so it's not hard to simulate those using computers these days."

Still, a direct observation is crucial in confirming a theory, so the astronomers studied what they were seeing in great detail. In this case, they

> "WE'D POINTED ALMA AND THE VLA TO Z CMA AT THE TIME TO STUDY ITS STREAMER, AND THE FLYBY OBJECT JUST SHOWED UP IN THE PHOTO" RUOBING DONG



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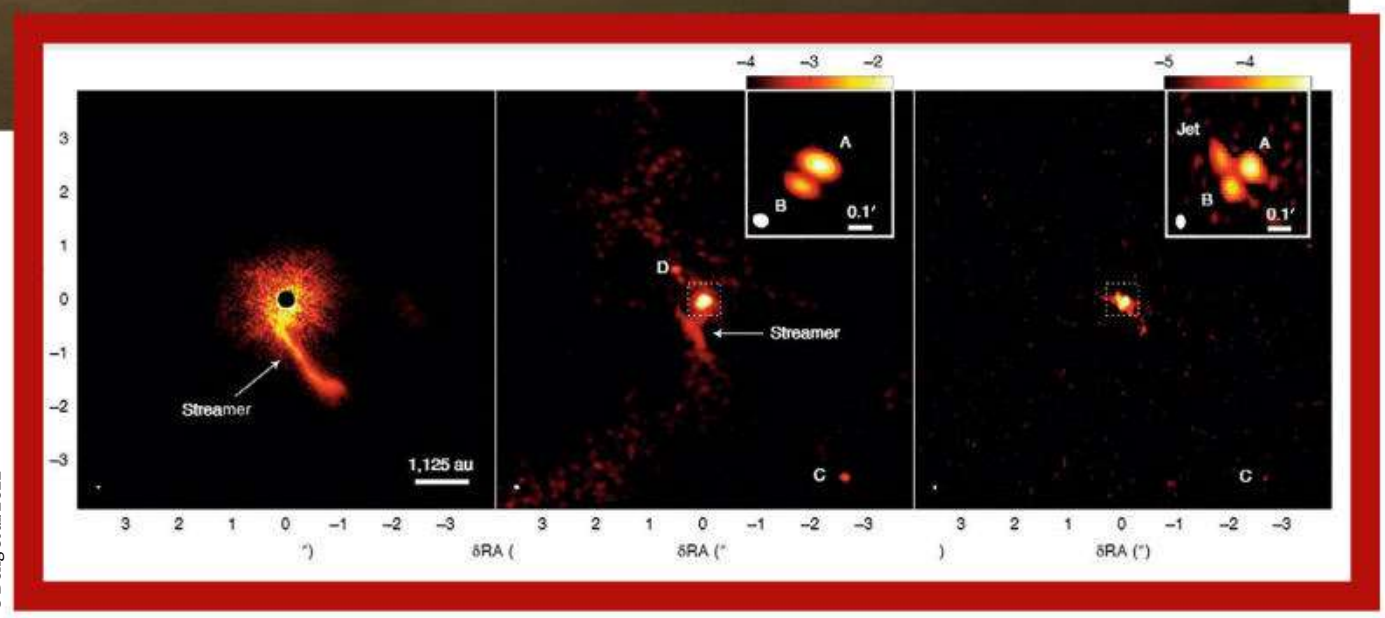

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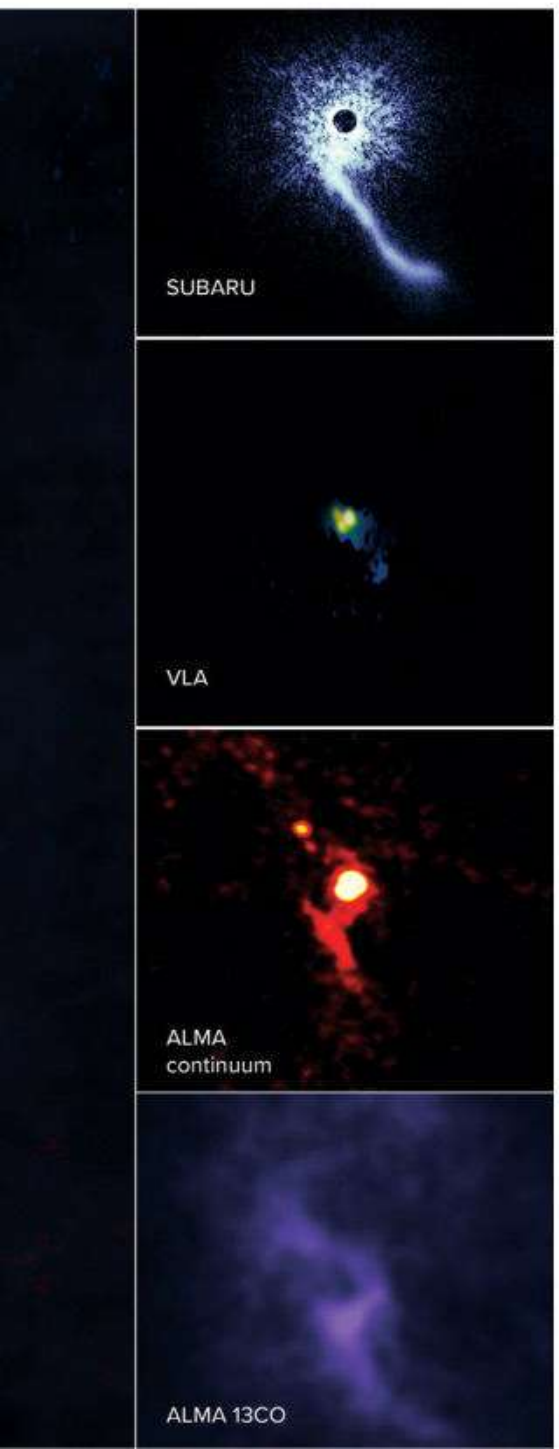

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Above: Stellar flybys have been theorised for a while. The disc surrounding UX Tauri is believed to have been perturbed by the flyby of another star

Right: The streamer is visible in these images, captured at different wavelengths

could see that close encounters between young stars harbouring discs can occur in reality. "Flyby was just one of the few hypotheses we formed to explain the observation," Dong says. "After studying the system in more detail, we narrowed down on this hypothesis."

The observation is being seen as yet another step towards a better understanding of how interactions influence the way a star system forms and evolves. In the case of Z CMa, astronomers are observing a complex binary system that's only 300,000 years old, very much in its infancy. There are no planets there as yet – at least none that astronomers know of – but the stars are in a phase of very high mass accretion. The stars are also shining incredibly brightly, with one being 1,300 times as luminous as the Sun and the other 2,400 times as luminous. "The most prominent feature produced by the intruder is the long streamer seen in the near-infrared image taken by the Subaru Telescope [based at the National Astronomical Observatory of Japan]," says Dong. "It's roughly 2,000 astronomical units in length – one AU being the distance between the Sun and Earth – and that is pretty large by Solar System standards. But the most significant impact, at least to me, is that it shows flyby events do occur in nature."

The findings were published in *Nature Astronomy* in January 2022 in an article entitled *A likely flyby of binary protostar Z CMa caught in action*. The scientists explain that most disturbances of this nature tend not to happen by intruders, but by sibling stars that are close by being pulled towards each other. The gravitational attraction causes material from the protoplanetary discs to be torn away, but during observations of Z CMa the streams didn't appear to have been affected by that kind of event. "We're not 100 per cent sure that the intruder was not bound to the star, but we think it's most likely," says Dong. "To be sure of that, we need to take multiple photos of the system and trace out the trajectory of the

object – in other words, we need a 'video'. That may be possible in the future."

Instead, the hypothesis that the intruder was not part of the star system has been made on the basis of how the streams look. They have spirals, warps and shadows, for example, that point towards them being caused by an object flying by. These are the kinds of things that were predicted by the computer simulations, but now they are there to see in real life. "We are basing our argument on the morphology of the system," Dong affirms.

So what have the scientists seen? "Long story short, the shape of the streamer is quite straight, and it's relative position with respect to the intruder implied the unbound nature of the intruder," Dong continues. "In other words, if the intruder was bound, we would expect the streamer to look different. What we have been doing is figuring out what happened in the system based on the morphology in images, having seen the intruder show up in the photo."

The key thing now is to work out how events such as intruder flybys affect a star system's evolution. Since there are no planets as of yet, could the flyby event change how they end up being formed by impacting on those gaseous circumstellar discs? To what degree are the systems being shaken, and are the effects positive or negative, perhaps bringing together certain material needed to create a planet or else destroying what was about to form? "You know, in science, certain things may have been predicted to occur in theory, but the best way to convince everybody that it exists is still to actually find it in nature," says Dong. "It's like when Einstein told us atoms would release a huge amount of energy when they're split. There were some doubts, but tests from 1938 onwards and the first detonation of a nuclear weapon on 16 July 1945 cast any doubts aside. Hopefully our discovery also puts doubts aside. We want it to excite people and inspire more studies on flyby events."

And that's certainly going to happen. As Dong describes, astronomers weren't hugely surprised that flyby events occur in nature, but having proof now steps things up a gear. "To be fair, Z CMa is not the first system that has been hypothesised to have experienced a flyby event," Dong continues. "Astronomers have also proposed a few other systems in the past, but Z CMa, in our opinion at least, provides the most comprehensive multi-wavelength evidence of a flyby event."

One potential effect of a flyby is the impact it can have on the heat output of a star. In

FINDING AN INTRUDER

The object that broke into the star system made a bit of a mess

1 THE INTRUDER OBJECT

The scientists discovered a source of light – called a point source – that showed an object is likely to have closely passed the protoplanetary disc and pulled a stream of gas from it. It's about 4,700 AU from Z CMa.

2 FLEDGLING STARS

The protoplanetary disc surrounds the Z Canis Majoris star system. It's been discovered that the intruder was likely not part of this system and came from elsewhere.

3 PROTOPLANETARY DISC

When stars form, lots of leftover material ends up orbiting in a disc around them. The reason why the intruder is intriguing is because it has disrupted the disc, and it's from this material that planets form.

4 THE STREAMER

Astronomers have known about the streamer for a while, but observations from ALMA, the VLA and the Subaru Telescope have shed fresh light on its cause. Who knows what effect the intruder will have on the disc.

© ESO

Above: ALMA helped scientists studying Z CMa's streamer make a stunning breakthrough

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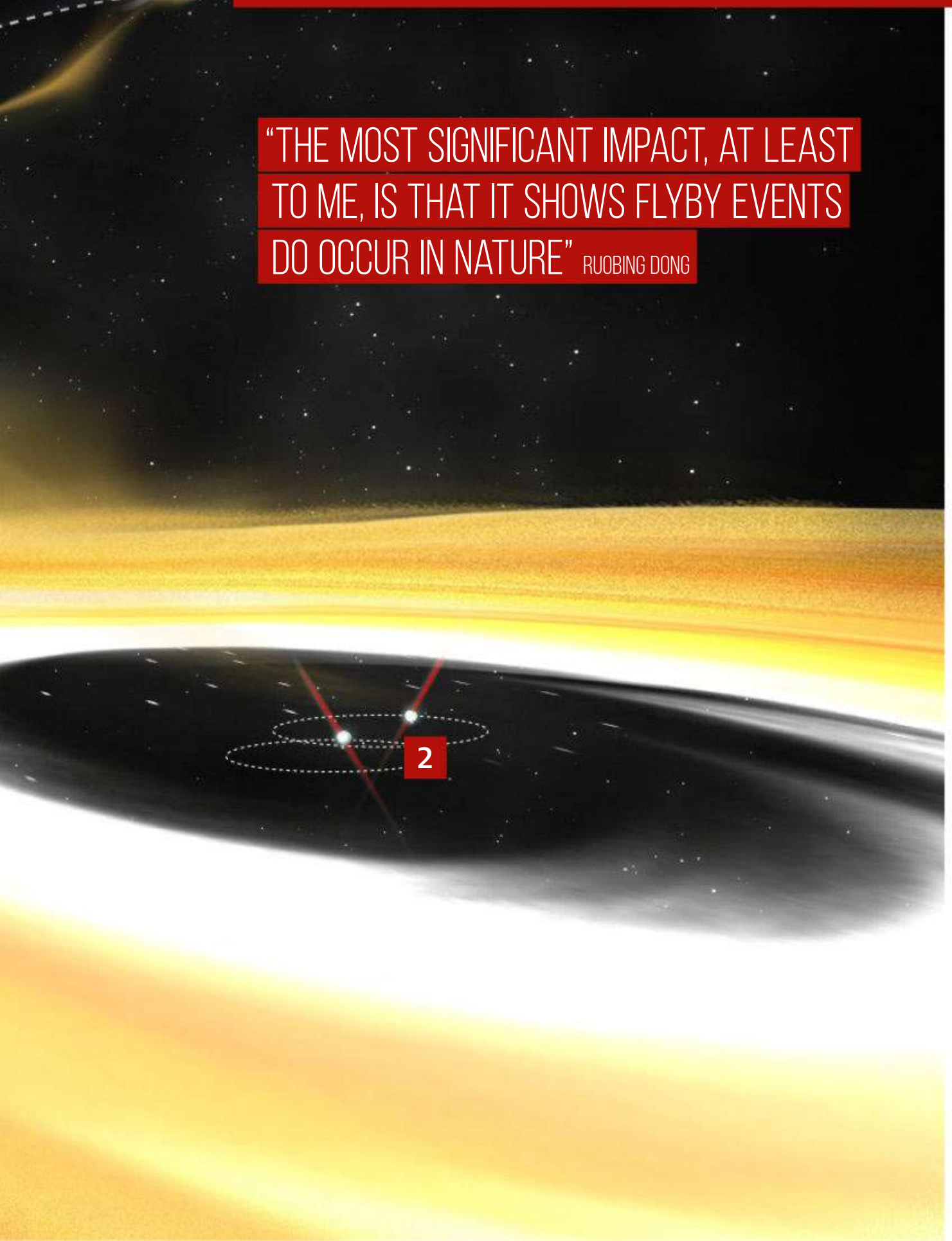

"THE MOST SIGNIFICANT IMPACT, AT LEAST TO ME, IS THAT IT SHOWS FLYBY EVENTS DO OCCUR IN NATURE" RUOBING DONG

2

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THREE POTENTIAL EXPLANATIONS

Astronomers sought to explain Z CMa's streamer, coming up with various theories for it

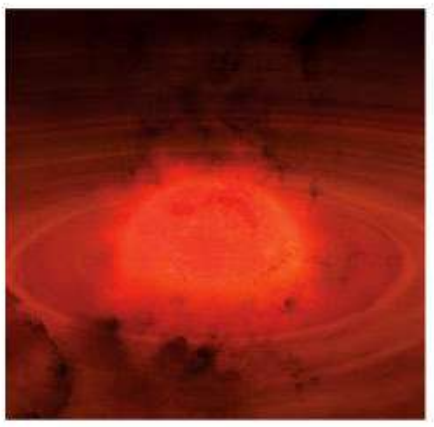
A SPIRAL ARM

Some have theorised that the long filament-shaped extension from the protoplanetary disc is a spiral arm produced by gravitational instability. In such circumstances, the arms would appear nearly symmetrical in scattered-light imaging.

© ALMA

MOLECULAR OUTFLOW

If a molecular outflow – an energetic mass ejection which happens in early star system formation – interacts with the surrounding material, light could be scattered off the walls of a cavity, producing scattered light that projects far from the stars.



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AN INTRUDER

It now seems far more likely, given the observation of a small point of light in the streamer, that an object which isn't bound to the system has caused a disturbance during a flyby. This disturbance would have removed material from the surrounding disc.

© NASA/JPL-Caltech

Right: Monitoring the impact of the intruder could help clear up mysteries about the Solar System's formation

Below: The VLA is made up of 27 radio antennae in a Y-shaped configuration in New Mexico

TAP HERE TO PLAY

© NASA/JPL

their research paper, the scientists pointed out that "Z CMa is a 'double burster', as both binary components undergo accretion outbursts which may be facilitated by perturbations to the host disc by flybys". This means that the flybys could be causing the binary protostars' accretion rate to rapidly increase, with the stars becoming brighter. It's possible that this would also increase the distance of the frost line.

The frost line is the distance from a central protostar where it becomes sufficiently cold for volatile compounds such as ammonia, carbon dioxide, carbon monoxide, ethane, hydrogen sulphide, methane and water to condense into solid ice grains. Here in our Solar System, the frost line is the marker between the terrestrial planets and gas giants. If a flyby object causes an accretion outburst, however, ices at the existing frost line could melt or evaporate. All sorts of chemistry and physics could result.

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> "THINGS MAY HAVE BEEN PREDICTED TO OCCUR IN THEORY, BUT THE BEST WAY TO CONVINCE EVERYBODY THAT IT EXISTS IS STILL TO ACTUALLY FIND IT IN NATURE" RUOBING DONG

There's every chance this happened in our Solar System, and why things are as they are drives astronomers to want to discover more. Dong and his team are also intrigued to discover the identity of the intruder object, but it's likely they're going to have to wait a little while longer before they know that for sure. The smart money is on it being a young stellar or sub-stellar object. "A planetary-mass object may be a bit too low mass to cause the effect," says Dong. Sub-stellar objects are more massive than planets but less massive than a star, and include brown dwarfs.

"It's all a big unknown," Dong admits. "It's the first time, to our knowledge, for humans to ever see that object in the Z CMa system, but we think it's most likely to be a young stellar object. Even so, other observations will be needed before we say something more certain than that. There's a tentative plan to use the newly launched James Webb Space Telescope to follow up on this object. It may be able to take a spectrum of the object, which will tell us a lot more."

This is only the beginning. As well as Webb, other telescopes will one day be able to shed more light on the object – one of which is a planned upgrade to ALMA's Band 6 receiver. It may even be that other flyby intruders are discovered in other star systems as the technology improves, which paves the way for even more studies and paths to explore. As Dong says: "The next generations of these technologies will open windows on the universe that we have only dreamed of."

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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PHYSICS PUZZLE ALMOST CRACKED USING DRUNKARD'S WALK

The three-body problem that's plagued science since the days of Isaac Newton is closer to being solved

Reported by Ashley Hamer

A pair of Israeli researchers used the 'drunkard's walk' to calculate the outcome of a cosmic dance between three massive objects – the so-called three-body problem. For physicists, predicting the motion of two massive objects, like a pair of stars, is easy. But when a third object enters the picture, the problem becomes unsolvable.

When two massive objects get close to each other, their gravitational attraction influences the paths they take in a way that can be described by a simple mathematical formula. Adding a third object isn't so simple; the interactions between the three objects become chaotic.

Instead of following a predictable path defined by a formula, the behaviour of the three objects becomes sensitive to 'initial conditions' – that is, whatever speed and position they were in previously. Any slight difference changes their future behaviour drastically, and because there's always some uncertainty in what we know about those conditions, their behaviour is impossible to calculate far out into the future.

In a new study, scientists used the frustrating unpredictability of the three-body problem to their advantage. "[The problem] depends very sensitively on initial conditions, so essentially it means that the outcome is random," said Yonadav Barry Ginat, a doctoral student at the Technion-Israel Institute of Technology. "But that doesn't mean that we cannot calculate what probability each outcome has."

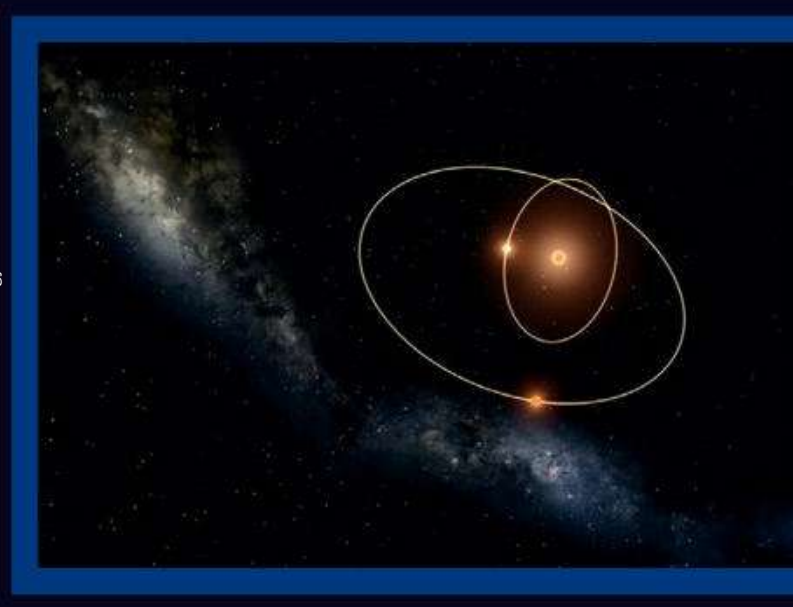
To do that, they relied on the theory of random walks – also known as the 'drunkard's walk'. The idea is that a drunkard walks in random directions, with the same chance of taking a step to the right as taking a step to the left. If you know those chances, you can calculate the probability of the drunkard ending up in any given spot at some later point in time.

The scientists looked at systems of three bodies where the third object approaches a pair of objects in orbit. In their solution, each of the drunkard's 'steps' corresponds to the velocity of the third object relative to the other two.

"You can calculate what the probabilities for each of those possible speeds of the third body are, and then you can compose all those steps and all those probabilities to find the final probability of what's going to happen to the three-body system in a long time from now," Ginat said, meaning whether the third object will be flung out for good, or whether it might come back in another orbit, for instance.

But the scientists' solution goes further than that. In most simulations of the three-body problem, the three objects are treated as so-called ideal particles, with no internal properties at play. But stars and planets interact in more complicated ways – just think about the way the Moon's gravity tugs on the Earth to produce the tides. Those tidal forces steal some energy from the interaction between the two bodies, and that changes the way each body moves.

Because this solution calculates the probability of each 'step' of the three-body interaction, it can account for these additional forces to more precisely calculate the outcome. This is a big step forward for the three-body problem, but Ginat says it's certainly not the end. The researchers now hope to figure out what happens when the three bodies are in special configurations, for example, all three on a flat plane. Another challenge is to see if they can generalise these ideas to four bodies.



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ASK Space

Our experts answer your questions

EXOPLANETS

How do scientists study the atmospheres of exoplanets?

Most exoplanets are too dim to detect directly, so scientists study their atmospheres indirectly by observing the effect the planetary atmosphere has on starlight. Transiting planets are the best for atmospheric studies. These are planets with orbits aligned so that the planet passes exactly between us and the planet's host star. While we can't actually see the planet, we know it exists because it blocks a fraction of the starlight: this dip in brightness is called a transit.

The planet's atmosphere appears as a translucent ring hugging the opaque disc of the planet. It acts as a filter: the chemicals present in the atmosphere absorb certain distinct, precisely defined colours of light. Quantum mechanics causes each chemical to create a characteristic absorption pattern of colours, which acts like a chemical fingerprint. This allows astronomers to measure chemical compositions by spreading light out into the spectrum of colours.

Astronomers study an exoplanet's atmosphere by comparing the spectrum from the star during a transit with the spectrum between transits. There will be extra missing light - filtered out by the atmosphere - made up of chemical fingerprints, revealing exactly which absorbing chemicals are present in the atmosphere.

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Carole Haswell, professor of astrophysics and head of astronomy at the Open University

Above: Transiting planets are best for atmospheric studies

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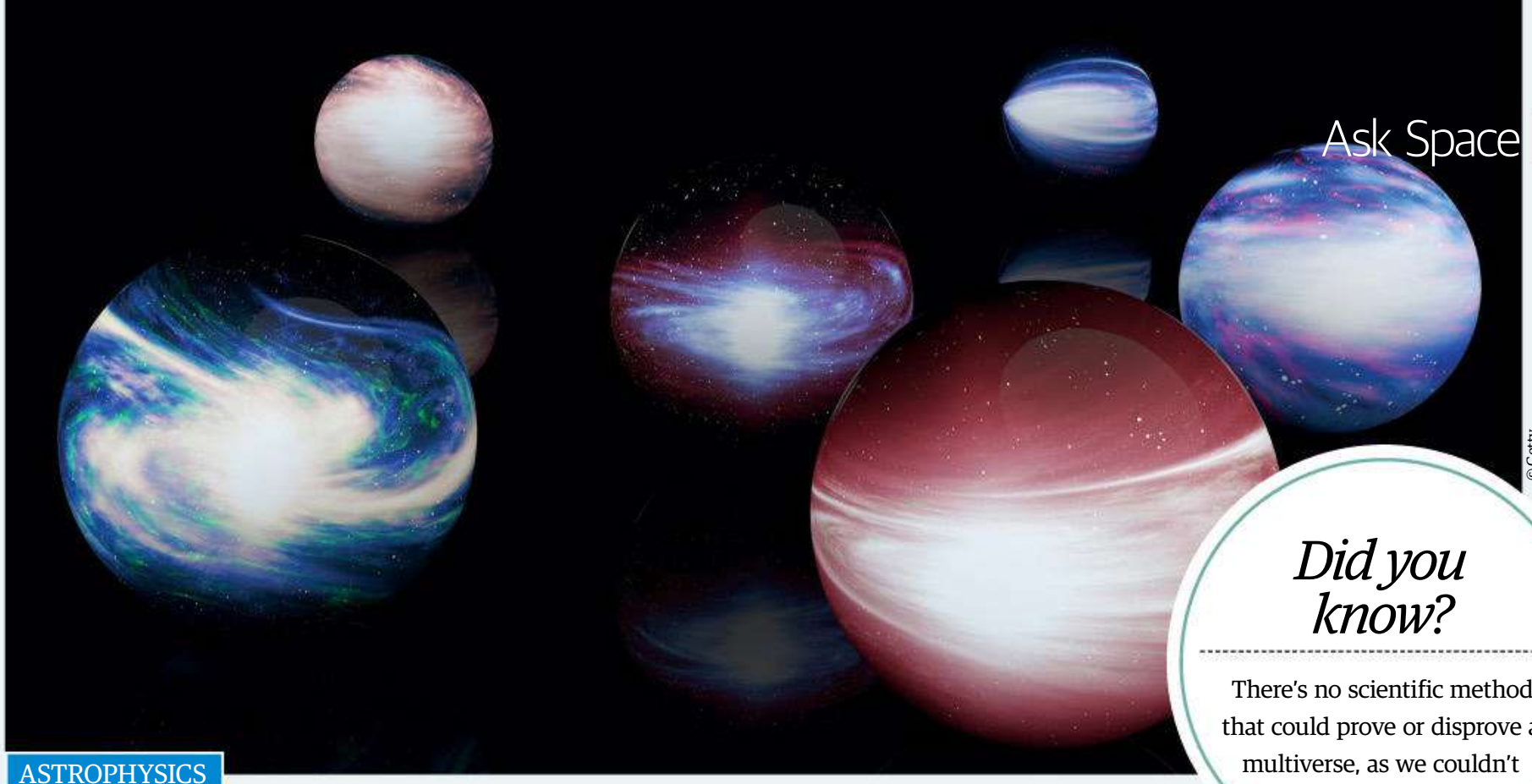

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Did you know?

There's no scientific method that could prove or disprove a multiverse, as we couldn't interact with them.

ASTROPHYSICS

Could we be living in a multiverse?

If the many-worlds interpretation of quantum theory is correct – and it's now taken very seriously indeed in theoretical physics and cosmology – then we definitely are living in a multiverse. The only question is what our multiverse is like. The many-worlds interpretation says that the multiverse contains worlds corresponding to every possible outcome of every quantum process. There are worlds where Schrödinger's cat is alive, and worlds where it's dead.

Given how quantum randomness underpins our entire lives, there are worlds where you win the lottery tomorrow, and worlds where it's just about to start raining humpback whales. But are there worlds with radically different laws of physics? That depends on what was going on in the very early universe. If the values of quantities like the cosmological constant and the coupling constant for the strong nuclear force were determined by a quantum process soon after the Big Bang, then the multiverse contains quantum worlds with all possible combinations of values of these quantities. Only a few combinations will prove suitable for life, of course. But then again it's no surprise that any observer should find themselves in a world like that. If the many-worlds interpretation is correct, then we might turn out to be living in a tiny hospitable corner of a gigantic and almost totally inhospitable multiverse.

Alastair Wilson, University of Birmingham

ASTROPHYSICS

Why do we make astronomical observations in different wavelengths?

Our eyes can only see in optical wavelengths, but objects in space shine across the electromagnetic spectrum. Stars, as an example, shine from beyond ultraviolet light, through optical into the infrared. Stars change temperature as they age, being born hot and gradually cooling down with time. Temperature determines the star's colour, but the colour variations we see in optical light alone are subtle. If we observe them in different wavelengths across the electromagnetic spectrum then we see much bigger differences, helping us pinpoint their age, as well as other properties. On a much larger scale, galaxies are made up of many different components, like stars, dust, gas and feeding black holes. Observing in many wavelengths is the only way that we can see all of these ingredients. Dust blocks the light from stars, but only when we observe galaxies in the far infrared – where it reradiates the energy absorbed from stars – can we know how much dust is there. Hydrogen gas is dark in the optical, but it glows in radio. Supermassive black holes are secretive – some are seen at all wavelengths, while others need radio or even X-ray to be uncovered.

Sabine Bellstedt, International Centre of Radio Astronomy Research

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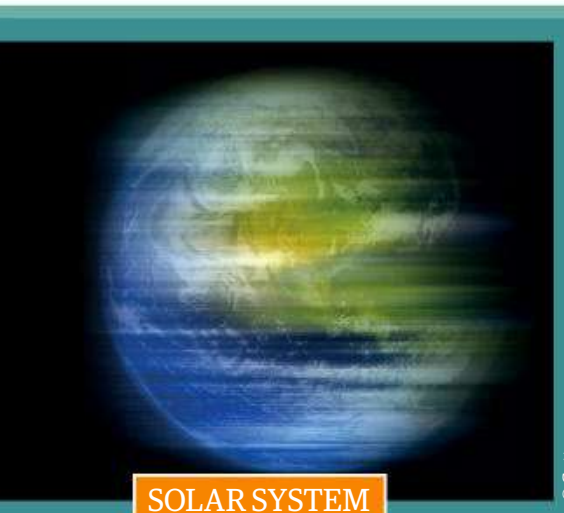
Above: Could the multiverse contain worlds corresponding to every possible outcome of every quantum process?

Right: Sunlight at different wavelengths

ASK Space

Our experts answer your questions



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SOLAR SYSTEM

Could Earth ever stop spinning? What would happen if it did?

Left: Earth won't stop spinning any time soon

Right: The Planck time is the shortest measurable time interval; it could be applied to the time the universe started to evolve after the Big Bang

Earth has been spinning since its birth 4.5 billion years ago. The only thing that could stop Earth's spin would be if another planet crashed into it. But it's more likely it would change the way Earth spins, not stop it. If Earth stopped spinning, you wouldn't suddenly be launched off into space. Gravity would still keep you firmly on the ground. If we stopped spinning but continued to orbit the Sun, a 'day' would last half a year, and so would a night.

Our core is partly molten iron. The spinning motion of Earth turns this molten iron into a magnet and gives Earth a magnetic field. This protects us against harmful radiation from particles from the Sun and cosmic rays from outside the Solar System. Without the magnetic field, radiation would reach Earth's surface and make people ill. Some birds use this to find their way, so without Earth spinning, they'd get lost. If Earth didn't spin, the night sky would always show the same stars because you'd always be looking out in the same direction. This is very different from seeing the stars rise and set during the night and seeing different constellations at different times of the year.

Dr Jacco van Loon, Keele Observatory

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ASTROPHYSICS

What is the Planck time?

The Planck time is an incredibly small interval of time that emerges naturally from a few basic quantities in theoretical physics. When it was discovered by Max Planck at the end of the 19th century, it seemed to be no more than a scientific curiosity. But today it plays a tantalising role in our understanding of the Big Bang and the search for a theory of quantum gravity.

The US National Institute for Standards and Technology gives the value of the Planck time as 5.391247×10^{-44} seconds. In other sources, including Planck's original paper, you may find a slightly bigger value of around 1.35×10^{-43} seconds. Whichever value is used, the result is a time interval that's unimaginably tiny in the context of everyday experience.

A nanosecond, often used colloquially to mean 'a very short time', is 0.000000001 seconds. But the Planck time has no fewer than 43 zeroes. It's the time it takes light to travel one Planck length, which is around a hundredth of a millionth of a trillionth of the diameter of a proton.

Dr Andrew May, science writer and author

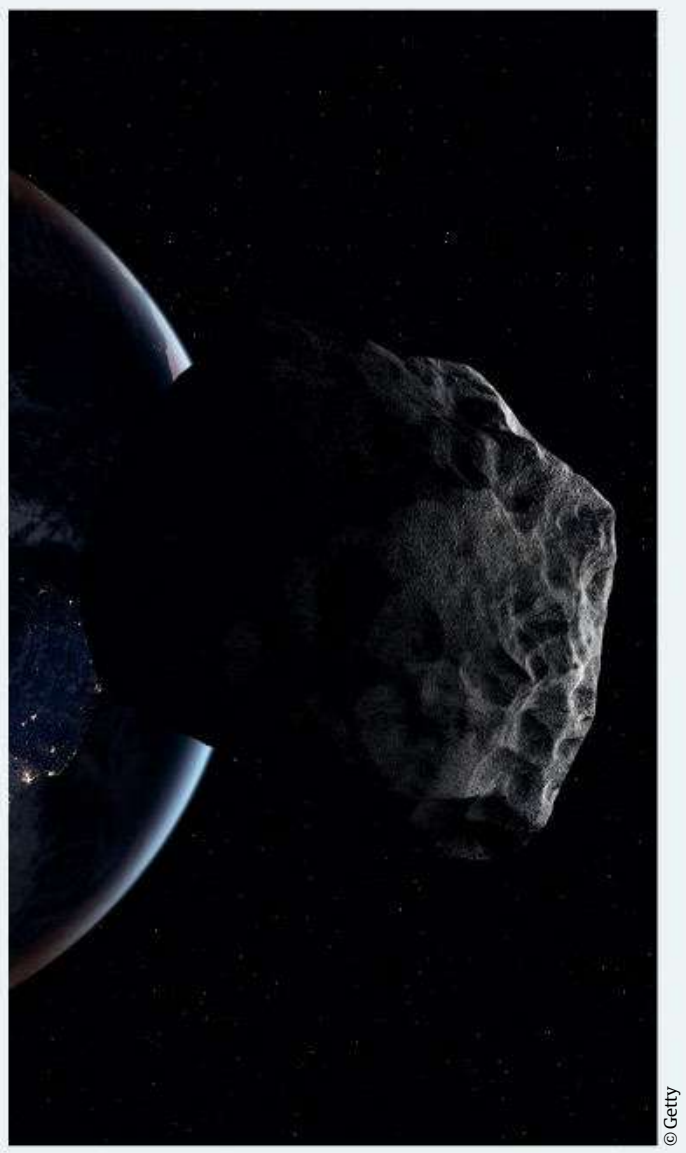
SOLAR SYSTEM

How did crocodiles survive the asteroid that killed the dinosaurs?

There are two main reasons. First, crocodiles can live for a very long time without food. Second, they lived in places that were the least affected – like rivers, lakes and coasts – when the asteroid hit Earth. About 66 million years ago, dinosaurs ruled Earth. But then a massive asteroid, more than nine kilometres (5.6 miles) wide, slammed into the shallow sea near what is now Mexico. The explosion from this was so huge, it led to global earthquakes, tidal waves, bushfires and even poisonous rain. Also, the impact threw up massive amounts of dust into the sky, blocking out the Sun for many months and sending Earth into a long, dark and freezing winter. Without sunlight, the green plants died, followed by the plant-eating animals that ate them to survive and the meat-eaters that ate the plant-eaters. But crocodiles famously survived the asteroid.

Right: Unlike dinosaurs living on the land, crocodiles in a river would not have starved as soon as the green plants died out

Mike Lee, professor in evolutionary biology, Flinders University



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SPACE EXPLORATION

Why can't we put a space station on the Moon?

One reason we haven't built a space station on the Moon is that we don't send people there very often. Space exploration company SpaceX is creating newer and bigger rockets that are capable of taking the weight of astronauts to the Moon. NASA is also planning new missions to take astronauts back to the Moon. However, there is a big difference between a short trip and building a space station on the Moon, which is extremely difficult. One way to do it would be to build it in pieces on Earth, take the pieces to the Moon and assemble them there. This would be like how the International Space Station was built: pieces were taken into space and then put together by astronauts aboard the Space Shuttle.

However, the International Space Station is only 250 miles [400 kilometres] from the surface of Earth. The Moon is 238,850 miles [384,400 kilometres] away on average. Each trip to the Moon would take about three days and would require incredible amounts of fuel, potentially adding to climate problems on Earth.

We might not even need a base on the surface of the Moon at all. Instead NASA is planning to build a satellite to orbit the Moon. Rockets launching from the lunar surface use more fuel to escape the Moon's gravity, but this wouldn't be so difficult from a satellite. This means it would be even better than a base on the Moon, and a gateway for missions heading further into the Solar System.

Ian Whittaker, senior lecturer in physics at Nottingham Trent University

Below: A space station on the Moon could be very useful, but very difficult to build

Did you know?

With water present on the Moon, some companies want to establish a mining base to extract it for fuel and human use.

© Getty

Focus on

PENTAGON LAUNCHES NEW UFO OFFICE

A new office in the Pentagon will investigate sightings of unidentified flying objects – but longtime extraterrestrial enthusiasts are sceptical

Reported by Stephanie Pappas

Putting the new Unidentified Aerial Phenomena program in the purview of the office of the Under Secretary of Defense for Intelligence & Security has some ufologists upset, as they don't exactly trust the US military to reveal whatever truth is out there.

"This is a subject with a provable history of secrecy, and anything that lacks a new openness about the information is subject to possibly inappropriate control," Ron James, a spokesperson for the nonprofit Mutual UFO Network, which investigates such sightings, said.

The creation of the new office was codified in the National Defense Authorisation Act, passed in December, which simply calls for the "establishment of office, organisational structure and authorities to address unidentified aerial phenomena." The topic has received renewed interest in recent years after the publication of videos taken by US military pilots seeming to show objects moving at impossible speeds and executing complex aerial manoeuvres.

But whether these sightings are really unexplained technology is up for strenuous debate. US officials are mostly concerned about Earthbound threats, worrying that foreign governments might be making advances in flight technology right under the US military's nose.

"Our national security efforts rely on aerial supremacy, and these phenomena present a challenge to our dominance," said Senator Kirsten Gillibrand, who spearheaded the bipartisan measure. "The US needs a coordinated effort to take control and understand whether these aerial phenomena belong to a foreign government or something else altogether."

On the other hand, there are also possible non-technological explanations for many of the sightings. For example, a report of a 'bright green' UFO over Canada in July 2021 occurred during the Perseid meteor shower, which is occasionally known to produce bright-green streaks as meteorites burn up in the atmosphere. Also, a glowing 'doughnut' UFO photographed by a skywatcher in Switzerland could be an out-of-focus shot of a star. And the apparently physics-defying videos from the US Navy pilots seeming to show incredibly swift UFOs could be the result of an optical illusion called parallax, in which a video of a moving object taken by a moving camera accentuates the apparent movement of the object, making it seem to be going much faster than it actually is.

UFO debunker Mick West said that true UFO believers may have given Pentagon officials the publicity and political support they needed to do work that they probably wanted to do anyway – but not necessarily because military officials believe extraterrestrials are trying to make contact with humanity.

"If you read the text of this legislation, it seems to reflect concerns of the extraterrestrial hypothesis believers," West said. "Now the military is sort of forced to jump through some slightly silly hoops while doing serious work."

In other words, don't expect the office to employ Mulder and Scully. The new effort to investigate such claims will be called the Airborne Object Identification and Management Synchronization Group (AOIMSG). "The AOIMSG will synchronise efforts across the department and the broader US government to detect, identify and attribute objects of interest in special use airspace and to assess and mitigate any associated threats to safety of flight and national security," Department of Defense (DOD) officials wrote in the announcement of the program. "DOD takes reports of incursions – by any airborne object, identified or unidentified – very seriously, and investigates each one."

"ANYTHING THAT LACKS A NEW OPENNESS ABOUT THE INFORMATION IS SUBJECT TO INAPPROPRIATE CONTROL"

RON JAMES

x2 images © Getty

HOW TO SPOT THE INTERNATIONAL SPACE STATION

Written by Daisy Dobrijevic and Mathew Browne

© NASA

THE INTERNATIONAL SPACE STATION CAN BE SEEN FROM EARTH; YOU JUST NEED TO KNOW WHERE AND WHEN TO LOOK

The International Space Station (ISS) is a multinational laboratory orbiting 400 kilometres (248 miles) above our heads. It perhaps comes as no surprise that the ISS can easily be seen from Earth. The colossal structure reflects sunlight and appears as a bright, white pinpoint of light in the sky – typically the brightest object in the sky except for the Moon – and can even be spotted from the middle of a city. The ISS is therefore a great skywatching and astrophotography target for those living in urban and rural areas alike. Spotting the ISS requires no specialist equipment as it can be seen with the naked eye. All you need to know is where to look and when.

"The International Space Station's trajectory passes over more than 90 per cent of Earth's population," says NASA. The ISS zips around the Earth at an average speed of 28,000 kilometres (17,500 miles) per hour, completing 16 orbits per day. As the ISS orbits with an inclination of 51.6 degrees, if you live beyond 51.6 degrees north or south of the equator the ISS will never appear directly overhead. The ISS is only visible because it reflects sunlight. It isn't bright enough to be seen in the middle of the day, and the best time to view the ISS is either at dawn or dusk. Viewing opportunities of the ISS can vary between one sighting a month to several a week, depending on your location and the orbit of the ISS.

NASA's Spot The Station website is a great resource for quickly finding out upcoming ISS viewing opportunities. Simply pop in the location you wish to know for ISS sighting opportunities and let the website work its magic. It will tell you the time of the ISS flyover, along with how long it's visible, the maximum height it will reach in the sky and which direction it will appear and disappear from your field of view. You can even sign up for email or text alerts for when the space station is flying over so you'll never miss a viewing opportunity again. It's worth noting you will only get NASA's Spot The Station alerts when the ISS is passing over with a maximum height of at least 40 degrees – this is because the ISS will be visible above most landscapes at this height.

The ISS makes for a fun and interesting observing target in the night sky. With its location and movement tracked with great accuracy, as well as night sky alerts from NASA's Spot The Station website, it's perhaps one of the easiest objects to spot in the night sky. Budding astrophotographers from around the world have caught beautiful long-exposure photographs that show the ISS appearing to streak across the sky. To the ground observer, the ISS passing overhead will appear as a bright point of light moving quickly across the sky, similar to an aeroplane, but brighter and without the flashing lights.

Below: Once you have all your equipment in order, you need to plan the shot. Think about an interesting foreground for the image

© Getty

TIME ON THE ISS

The ISS completes an orbit in 90 minutes, so how do astronauts keep track of time? The ISS uses Coordinated Universal Time (UTC). It was selected as the time zone for the ISS because it's around the mid-point for all ISS partners.

CAMERA SETTINGS FOR PHOTOGRAPHING THE ISS

Though there's no concrete rule on settings, here are some pointers to find a setting that works for you. Set your camera to manual mode, which gives you full control over each setting.

Aperture needs to be as low a number as possible so your camera collects as much light as it can. We usually recommend shooting astrophotography scenes at f/2.8 or f/1.8 if your lens is up to the task. Shutter speed should be as long as possible without stars trailing. This is usually 8 to 20 seconds.

The ISO depends on your environment. In a brightly lit area such as a cityscape or if the Moon is up, it could be as low as 400. In rural, dark-sky areas, it may need to be as high as 3200. Many modern cameras will happily shoot at higher ISOs with very little noise.

Make sure continuous shooting is enabled so your images are captured consistently during the shoot. Always shoot raw, as it allows you to capture better detail and more dynamic range from your camera sensor. It also gives you much more data to play with during the editing process.

Since the path of the ISS can be calculated, this means that with some planning, the right gear and clear skies, it can be a striking subject to photograph. Photographing the ISS doesn't require specialist or expensive equipment. Since the ISS is a bright point of light in the sky, any lens will be able to capture it, but the faster the better. At the bare minimum you will need a DSLR or mirrorless camera with full manual control, a lens at a suitable focal length – to capture a good trail you'll need a wide-angle lens – and a tripod, the sturdier the better.

You will also need some kind of shutter release. This can be a cable plugged into your camera or a remote control that allows you to capture images without physically touching your camera. For the sharpest possible images, this is an important gadget to have in your arsenal. A dew heater is also a handy accessory to have on hand. These are inexpensive USB-powered devices that prevent moisture – ice, dew or fog – from forming on the front of your lens during your shoot. You are generally more likely to encounter this on longer shoots, such as capturing star trails, but you'd be surprised how quickly dew can form.

Once you have all your equipment in order, you need to plan the shot. First, consider the angle of the ISS pass. If it's arcing close to the horizon, then you may consider a wide-angle shot showing the arc juxtaposed with an interesting foreground. If the ISS passes directly overhead, you may want to capture the ISS as it meets the horizon, creating a vertical band of light in the completed image. Think about an interesting foreground for the image. If you're capturing a wide-angle arc, what can you include to anchor the image? If it's an overhead pass, can you line up the path of the ISS with a foreground object?

If you're looking for inspiration for photography locations near you, or ISS compositions to try out, then there are a few places to look. PhotoHound is a website for photographers to share information on attractive photo spots, how to get there and in what conditions, including astrophotography. If you have a particular location in mind, find it on Instagram and look at the most recent images. You don't want to travel to a shooting location to find the angle you want isn't accessible or the view is blocked somehow. Google Maps has great coverage on Street View which may allow you to visually compose your shot and do location scouting without leaving the house. Arrive at your location early and take plenty of test shots to ensure your composition will work. You'll want to have your settings ready to go when the ISS makes an appearance.

TAP HERE TO PLAY
"TO THE GROUND OBSERVER, THE ISS PASSING OVERHEAD WILL APPEAR AS A BRIGHT POINT OF LIGHT MOVING QUICKLY ACROSS THE SKY"

Right: With good timing, the right shot and editing, you can create an ISS masterpiece

© Alamy

To photograph the ISS, you'll need to capture a sequence of images – typically 8 to 20 seconds each depending on the focal length – which can be combined later to become a single streak of light. It's a similar process to photographing star trails. A flyover of the ISS can last a couple of minutes, so you may think it's sufficient to leave the shutter open for the duration, but this is a rookie mistake! There are two reasons to avoid this approach. Firstly, a capture of several minutes will almost certainly be overexposed. Secondly, if there are any stars in your image these too will start to create a light trail.

With the right planning and equipment – and of course clear skies – the ISS makes for an interesting and accessible observational and photography target. If the weather isn't on your side or you have an equipment mishap, don't fret, as you can always try again. With ISS flyovers varying between one a month to multiple a week, there's always another opportunity to spot the multinational laboratory zipping through the sky.

Daisy Dobrijevic
Staff Writer
Daisy is **All About Space**'s Staff Writer. She previously worked for *BBC Factual* as a researcher and *BBC Sky at Night* magazine as an editorial assistant.

Below: When you create your test shots, check your stars to ensure that they remain as sharp points of light. On the left is an image taken with a 150-second exposure, where the stars are trailing and overexposed, and on the right is an image taken with a ten-second exposure that has crisp, sharp stars

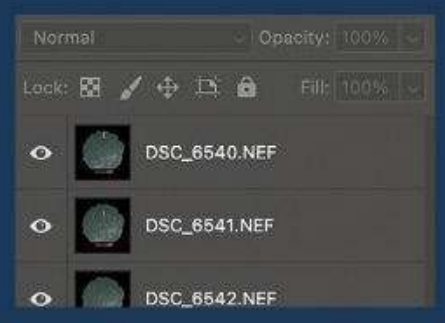
© Matthew Browne

FINAL IMAGE

Once you're happy that your image stack is complete, you may wish to continue editing to fix things like colour toning or dodging and burning your foreground. You can continue to edit it in Photoshop, or save it to process further using other image editors such as Lightroom or Luminar.

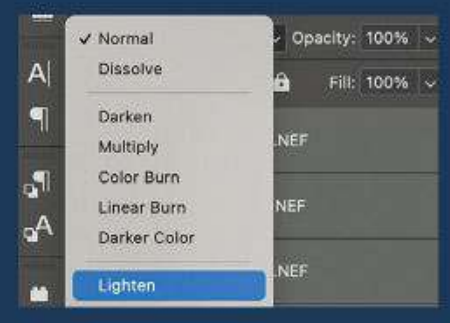
EDITING YOUR PHOTOGRAPHS OF THE ISS

Well done – you've captured an ISS pass! Your work isn't quite over yet, though. There's still the task of combining these images into one using a method called stacking. Adobe Photoshop makes this easy. Other software is available to blend ISS and other star trail images, such as Starstax (Mac and Windows) and Startrails (Windows). Below is our step-by-step guide for the Photoshop method.



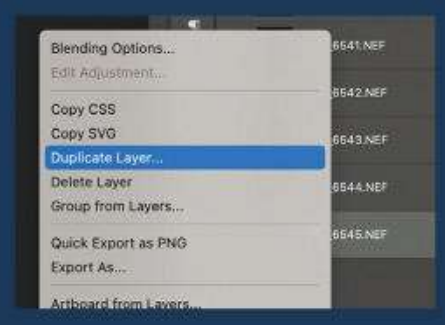
STEP 1

Take all your images and put them as separate layers in Adobe Photoshop.



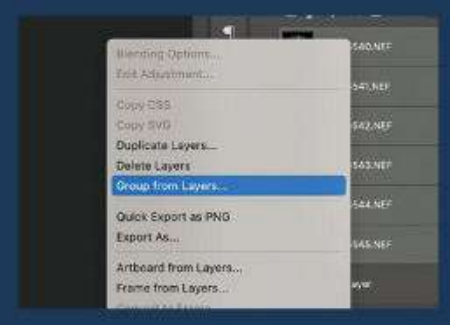
STEP 2

Select all the layers you have and set the blend mode to lighten.



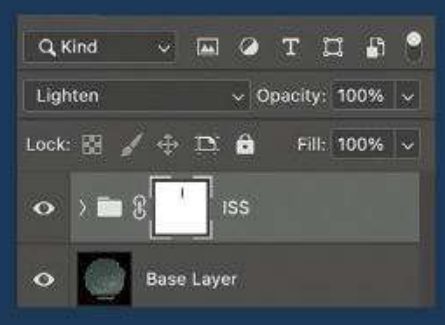
STEP 3

Duplicate one of the layers and save it as a new layer. You may want to call this 'Base Layer' for ease of reference.



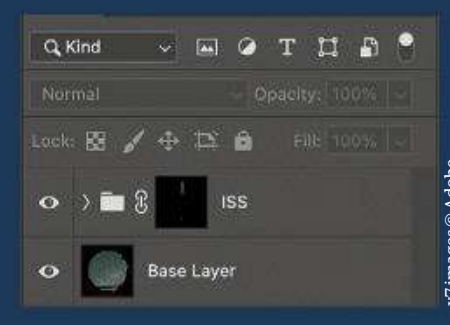
STEP 4

Select the rest of the layers and group these into a new folder. You may want to call this 'ISS' for ease of reference.



STEP 5

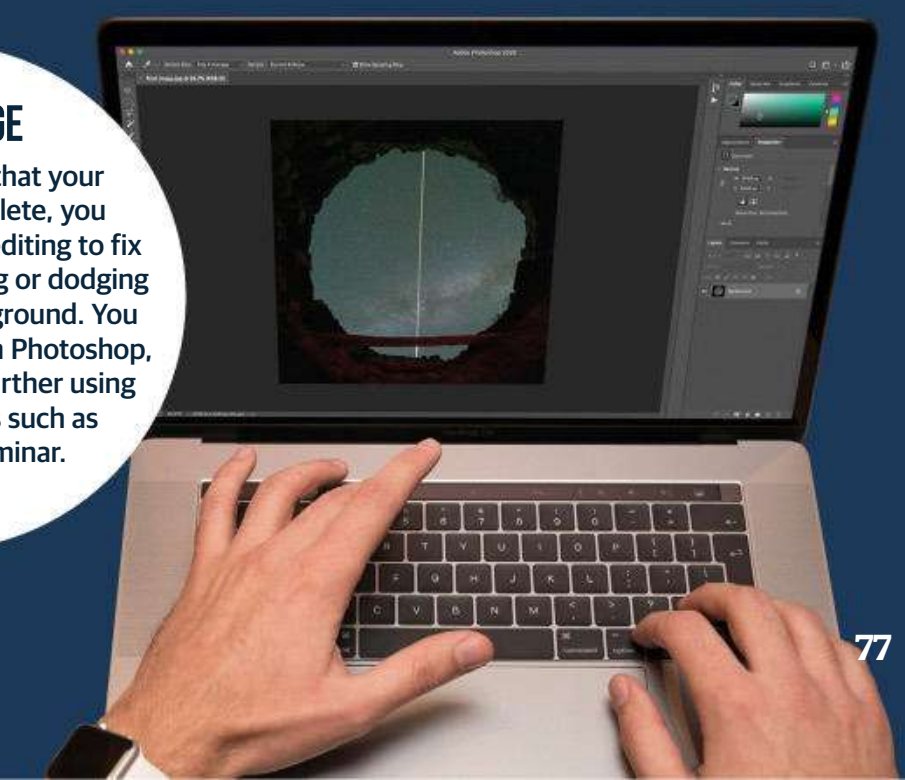
Add a layer mask. Click on this, then grab a black brush and paint onto the ISS trail. The ISS trail will be removed as you do this.



x7 images © Adobe

STEP 6

Finally, invert the mask. This is achieved by right clicking the mask. Now only the ISS trail will be overlaid onto your base image.



STARGAZER

WHAT'S IN THE SKY?

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"COMET 22P/KOPFF WILL MAKE ITS CLOSE APPROACH TO THE SUN, PREDICTED TO REACH +10.4"

RED-LIGHT FRIENDLY
In order to preserve your night vision, you should read our observing guide under red light

27 FEB
Conjunction between the Moon and Mars in Sagittarius

27 FEB
Conjunction between the Moon and Venus in Sagittarius

27 FEB
The Moon and Mars make a close approach, passing within 3°31' of each other in Sagittarius

Source: Wikipedia Commons © Chesnok

4 MAR
Conjunction between Mars and Pluto in Sagittarius

7 MAR
The Moon will pass in front of Uranus, creating a lunar occultation

16 MAR
Comet 22P/Kopff will make its closest approach to the Sun, predicted to reach +10.4

20 MAR
Venus reaches greatest elongation west in the dawn sky, shining brightly at -4.4

20 MAR
March equinox

JARGON BUSTER

CONJUNCTION

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

RIGHT ASCENSION (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

DECLINATION (DEC)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

MAGNITUDE

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

OPPOSITION

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

GREATEST ELONGATION

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

3 MAR

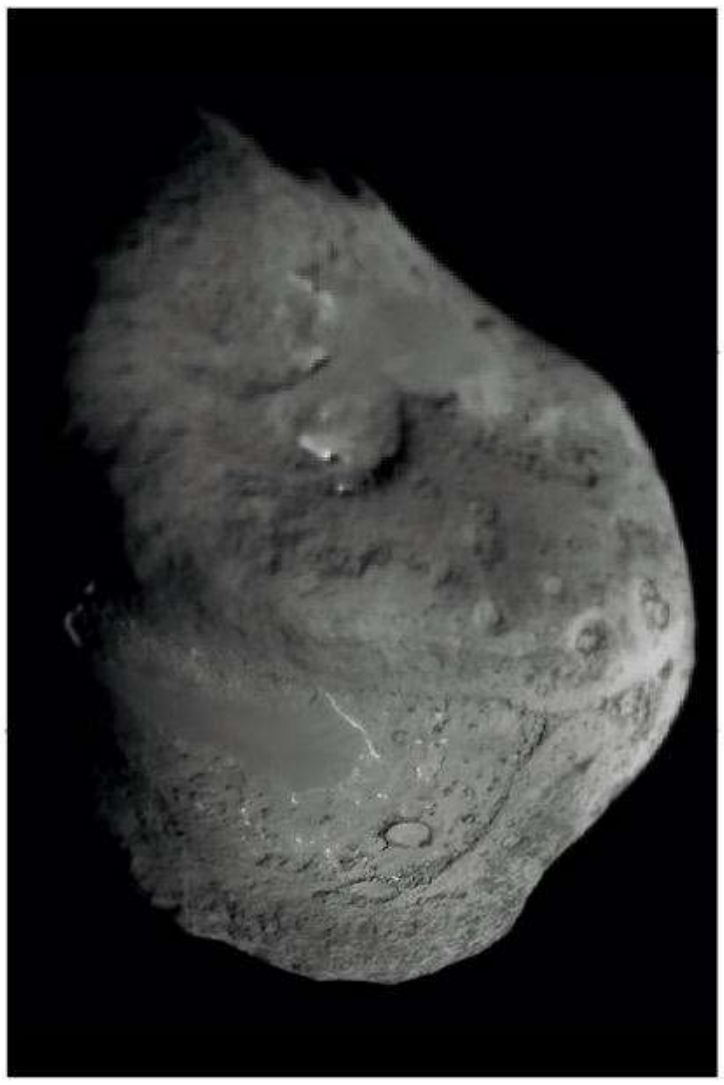
Comet 9P/Tempel will make its closest approach to the Sun, predicted to reach +11.2

7 MAR

The Moon and Uranus make a close approach, within 46.3' of each other in Aries

16 MAR

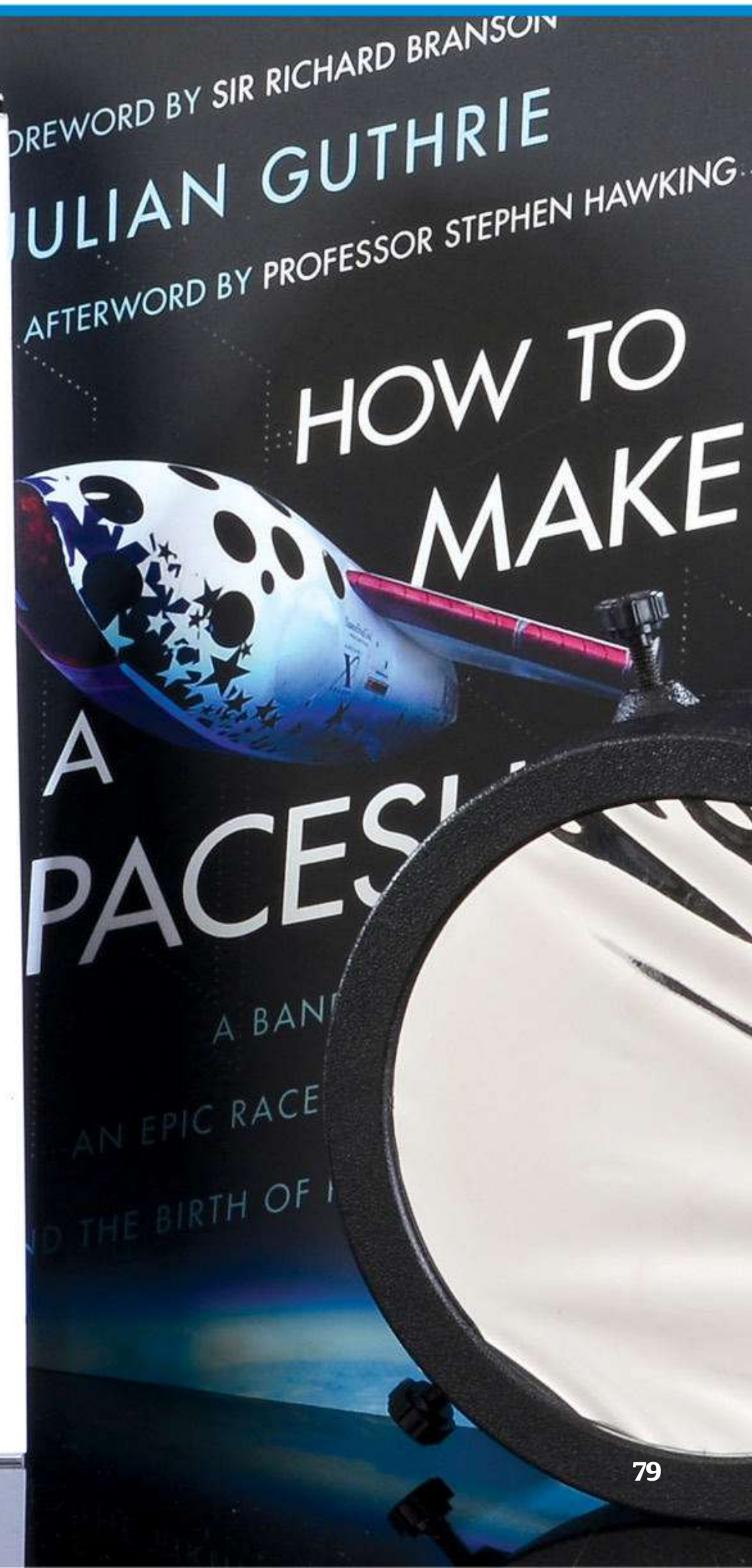
Venus and Mars make a close approach, passing within 3°53' of each other in Capricornus



©NASA

©Getty

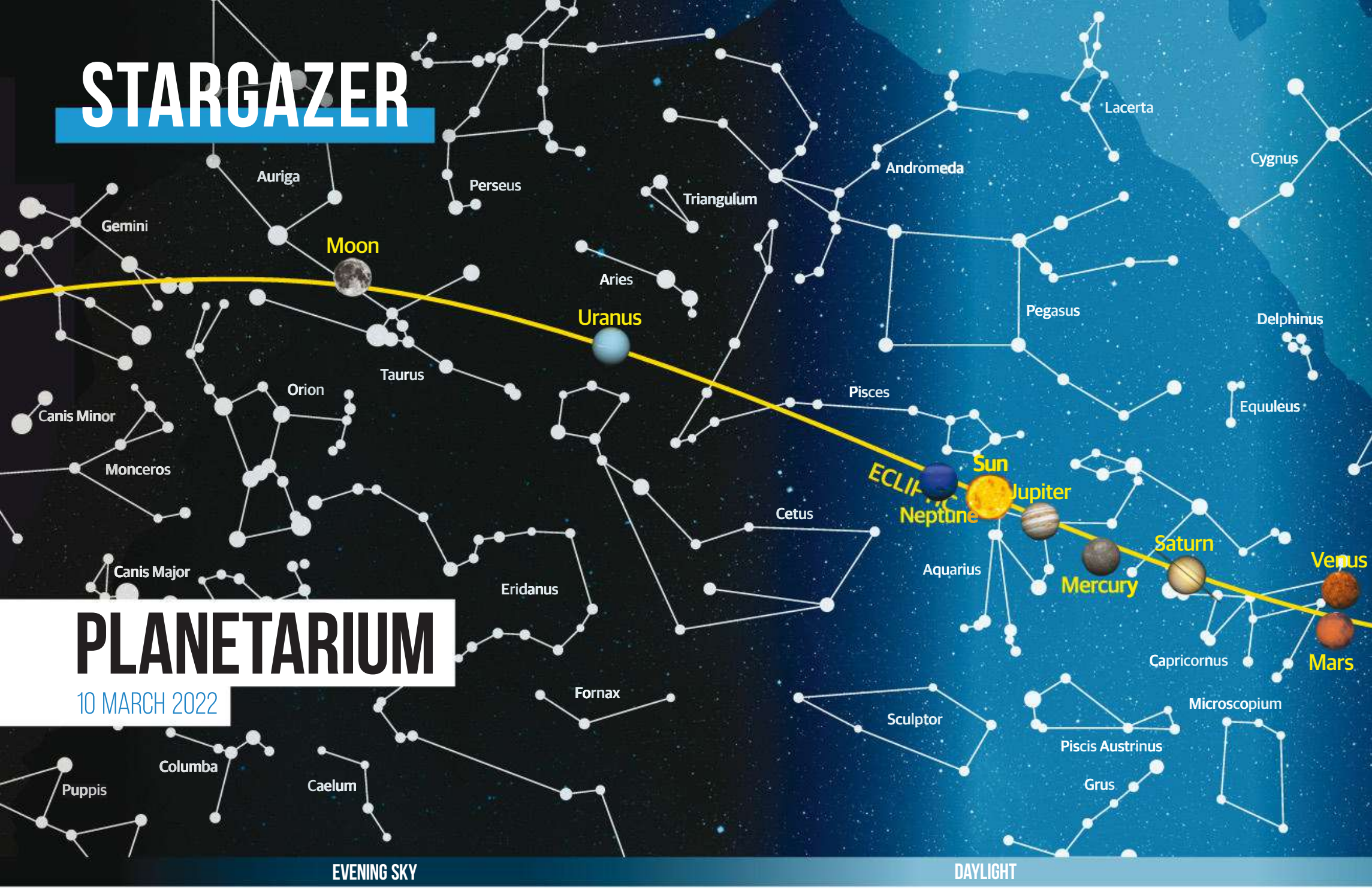
- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope



STARGAZER

PLANETARIUM

10 MARCH 2022



MOON CALENDAR

* The Moon does not pass the meridian on 17 March

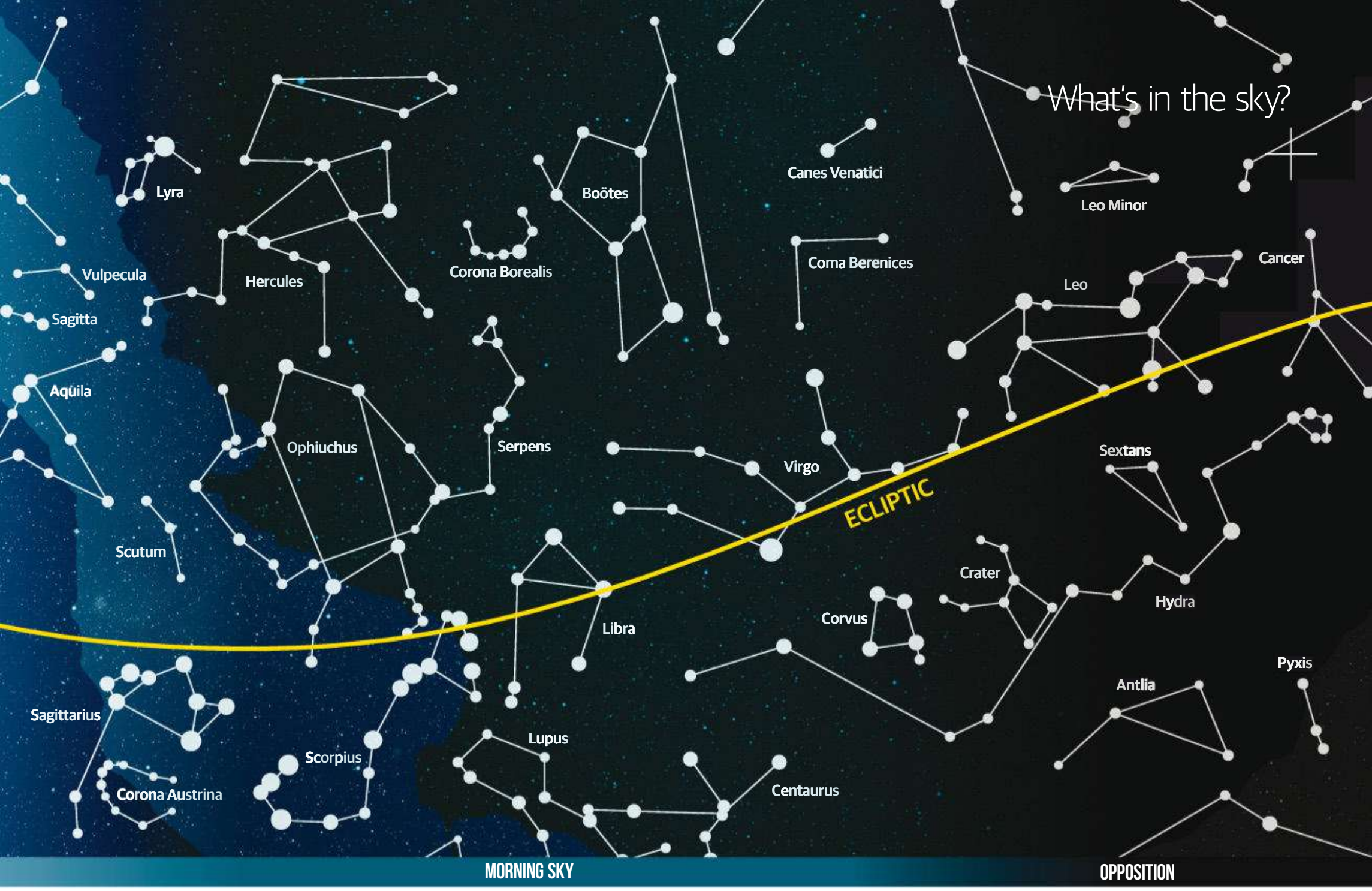
24 FEB 46.5% 02:13 10:10	25 FEB 34.8% 03:35 10:52	26 FEB 23.8% 04:46 11:50	27 FEB 14.4% 05:42 13:03			
28 FEB 7.0% 06:22 14:27	1 MAR 2.3% 06:51 15:54	2 MAR NM 0.2% 07:12 17:19	3 MAR 1.0% 07:29 18:40	4 MAR 4.2% 07:43 19:58	5 MAR 9.5% 07:57 21:14	6 MAR 16.5% 08:11 22:29
7 MAR 24.7% 08:26 23:43	8 MAR 33.8% 08:44 --:--	9 MAR 43.4% 00:55 09:07	10 MAR FQ 53.1% 02:04 09:37	11 MAR 62.7% 03:08 10:16	12 MAR 71.9% 04:02 11:06	13 MAR 80.4% 04:46 12:07
14 MAR 87.7% 05:20 13:17	15 MAR 93.7% 05:46 14:32	16 MAR 97.8% 06:06 15:49	17 MAR --:--%* 06:23 17:07	18 FEB FM 99.7% 06:38 18:26	19 MAR 99.3% 06:52 19:47	20 MAR 96.2% 07:07 21:10
21 MAR 90.6% 07:23 22:35	22 MAR 82.7% 07:44 --:--	23 MAR 72.9% 00:02 08:11	24 MAR 61.7% 01:26 08:48			

% Illumination
Moonrise time
Moonset time

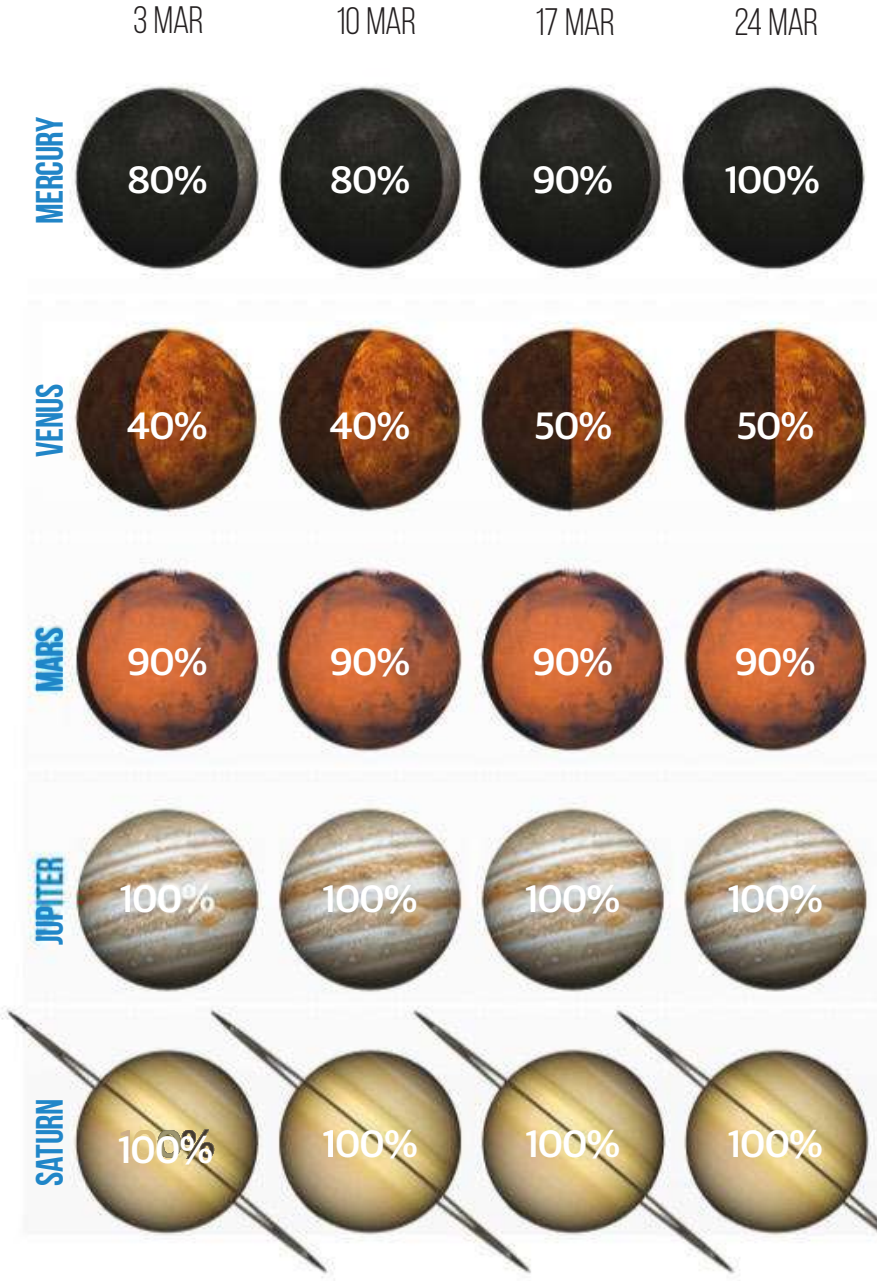
FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)

What's in the sky?



ILLUMINATION PERCENTAGE



PLANET POSITIONS

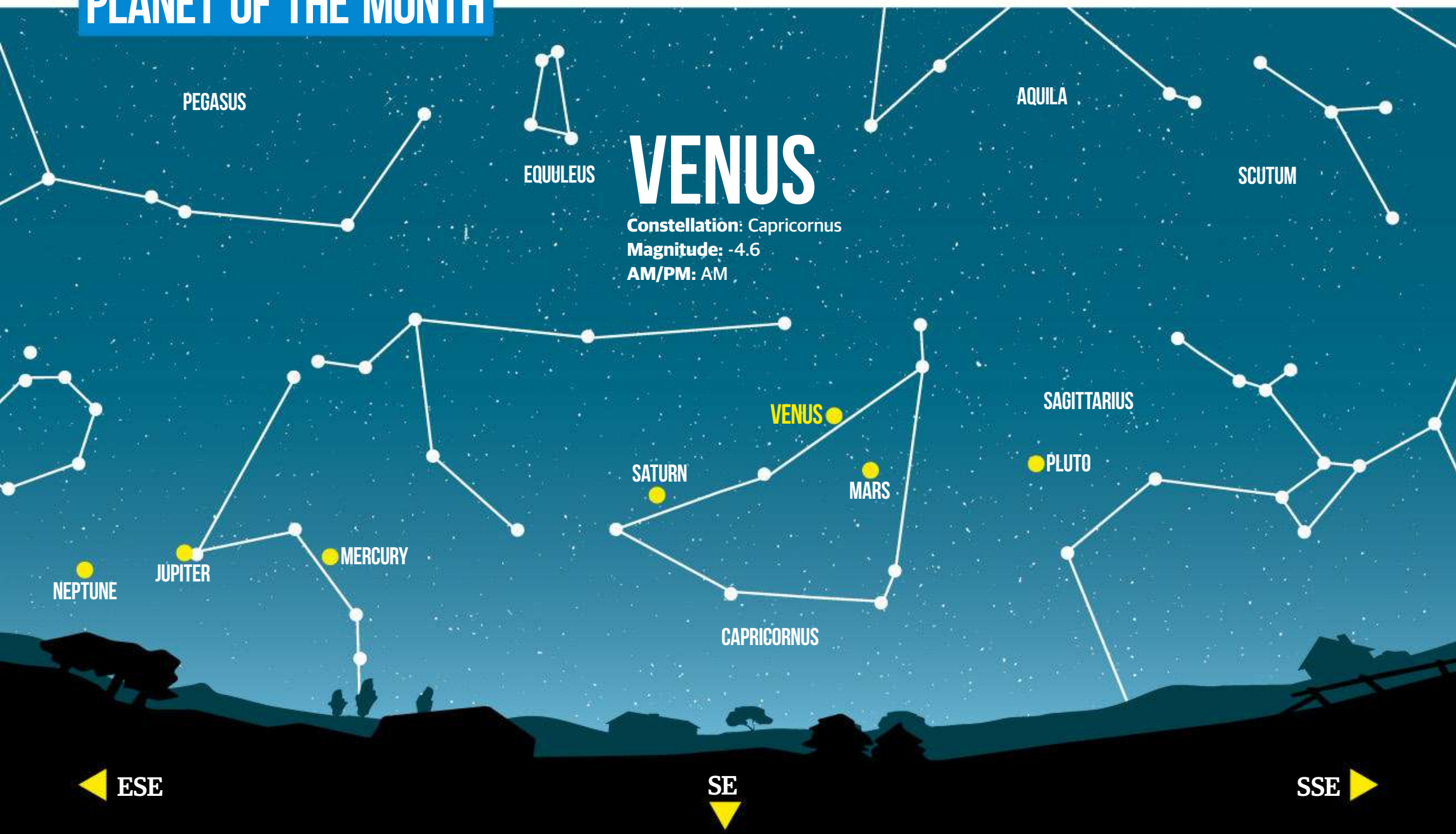
All rise and set times are given in GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
24 FEB	20h49m31s	-18°35'03"	Capricornus	-0.1	06:27	14:48
3 MAR	21h28m15s	-16°35'42"	Capricornus	-0.1	06:24	15:13
10 MAR	22h09m47s	-13°33'41"	Aquarius	-0.3	06:19	15:47
17 MAR	22h53m23s	-09°30'29"	Aquarius	-0.5	06:10	16:28
24 MAR	23h39m07s	-04°28'39"	Aquarius	-1.0	05:58	17:15
24 FEB	19h29m34s	-17°00'33"	Sagittarius	-4.6	04:56	13:40
3 MAR	19h52m36s	-16°51'32"	Sagittarius	-4.5	04:51	13:36
10 MAR	20h18m07s	-16°22'44"	Sagittarius	-4.5	04:45	13:37
17 MAR	20h45m22s	-15°31'54"	Sagittarius	-4.4	13:43	13:43
24 MAR	21h13m45s	-14°18'14"	Sagittarius	-4.4	04:32	13:51
24 FEB	19h35m49s	-22°23'40"	Sagittarius	+1.3	05:42	13:06
3 MAR	19h57m58s	-21°32'57"	Sagittarius	+1.4	05:30	13:07
10 MAR	20h19m56s	-20°31'31"	Capricornus	+1.2	05:17	13:10
17 MAR	20h41m40s	-19°20'01"	Capricornus	+1.2	05:02	13:13
24 MAR	21h03m08s	-17°59'10"	Capricornus	+1.1	04:46	13:16
24 FEB	22h56m24s	-07°49'33"	Aquarius	-2.0	07:25	18:03
3 MAR	23h02m42s	-07°10'48"	Aquarius	-2.0	07:00	17:46
10 MAR	23h09m00s	-06°31'47"	Aquarius	-2.0	06:35	17:28
17 MAR	23h15m16s	-05°52'44"	Aquarius	-2.0	06:10	17:11
24 MAR	23h21m29s	-05°13'51"	Aquarius	-2.0	05:45	16:53
24 FEB	21h22m32s	-16°17'39"	Capricornus	+0.8	06:44	15:37
3 MAR	21h25m44s	-16°03'21"	Capricornus	+0.8	06:18	15:14
10 MAR	21h28m50s	-15°49'23"	Capricornus	+0.8	05:52	14:51
17 MAR	21h31m49s	-15°35'54"	Capricornus	+0.8	05:26	14:28
24 MAR	21h34m39s	-15°23'02"	Capricornus	+0.8	05:00	14:05

THIS MONTH'S PLANETS

Venus is a striking sight in the dawn sky, taking the morning watch with Mercury, Mars and Saturn

PLANET OF THE MONTH



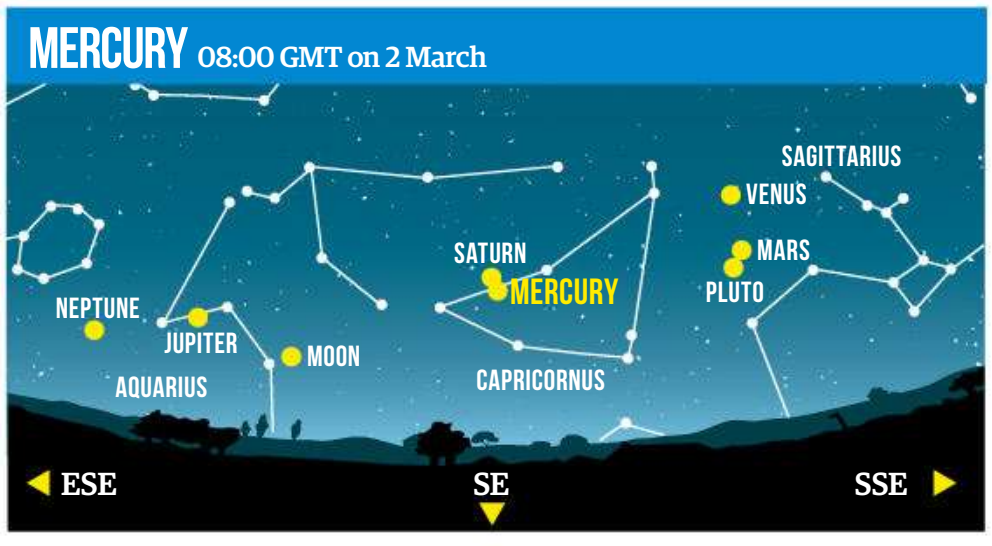
Having been a very bright but very low object after sunset at the end of last year, Venus has now well and truly swapped its 'evening star' hat for its 'morning star' one, and is a stunning sight low in the east before sunrise. Brighter than any other planet or star around it, at the start of our observing period it will be rising two hours before the Sun, giving observers the chance to see it shining in a still-dark sky.

If you get up early – or are still up after a long night – you'll see Venus before you see anything else, looking like a silvery-blue spark low in the sky, so bright it will shine through even serious light pollution. If you're lucky enough to live away from the streetlights, illuminated buildings and advertising signs that cause this light pollution, you'll have a simply stunning view of Venus – you might even see it casting a faint shadow.

Venus won't be on its own in the morning sky. At the end of February, look closely and you'll see a much fainter orange-red 'star' to Venus' lower right. This star is actually the planet Mars, and although it will be considerably fainter than Venus it will still be visible to the naked eye. Each morning from the end of February these two planets will appear a little closer together – not so much that it is obvious to the naked eye day by day, but after a few days you will notice it.

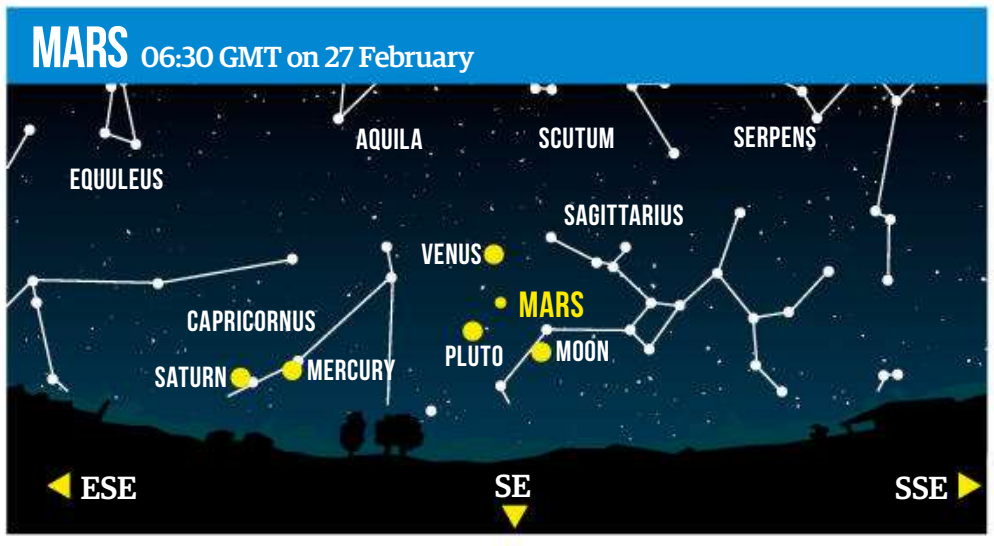
On the morning of 16 March the two planets will be less than four degrees apart. It's a shame that this close encounter will be happening when the planets are so low in the sky and dimmed by the approach of sunrise, but it will still be worth looking for with binoculars.

As our observing period comes to a close, Venus will form a tight triangle with Mars to the lower right and Saturn to the lower left in the predawn sky, but again our view of this celestial gathering will be diminished by their low altitude and the brightness of the sky; the Sun will rise just half an hour or so after the trio, so it's going to be extremely challenging to see them, and if your southeastern horizon is high or has any hills, buildings or trees on its skyline you'll have no chance at all.



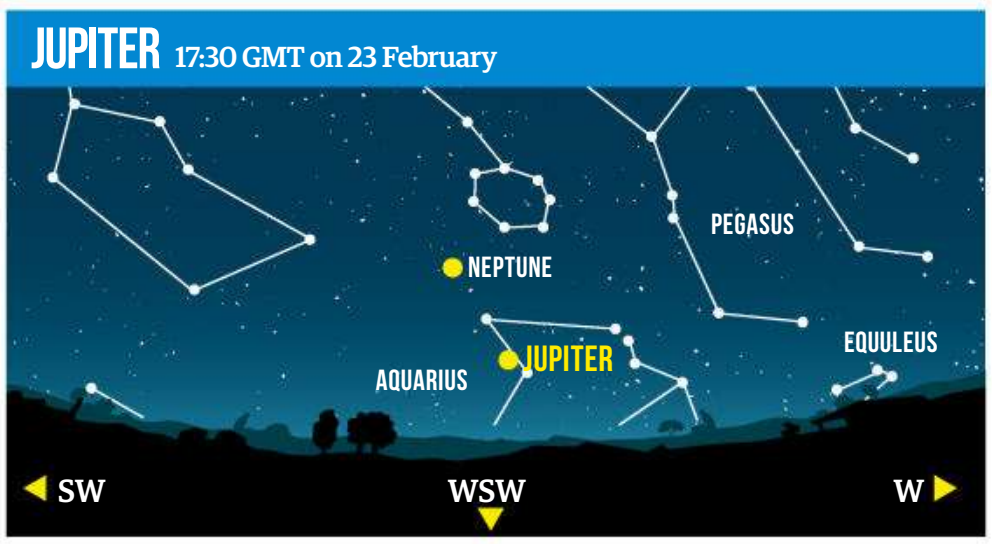
Constellation: Capricornus **Magnitude:** +0.0 **AM/PM:** AM

At the start of our observing period Mercury, closest planet to the Sun, will be a faint 'morning star' shining low in the southeast before sunrise, to the lower left of much brighter Venus. As the days pass it will brighten and its visibility will improve. It will be farthest from the Sun on the morning of 3 February, when it will be rising around an hour before the Sun.



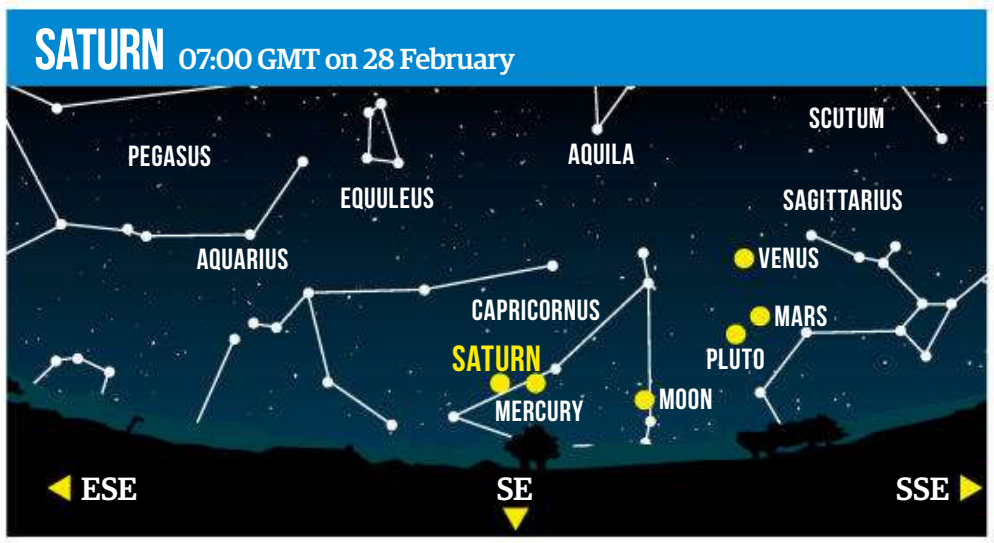
Constellation: Sagittarius **Magnitude:** +1.3 **AM/PM:** AM

Mars will be visible in the morning sky, but it will be so low in the sky that it will be hard to see. Mars will be close to brighter Venus, which will help you find it, and as February slides into March the two planets will steadily move closer together in the sky. They are at their closest before dawn on the morning of 16 March, when they will be less than four degrees apart.



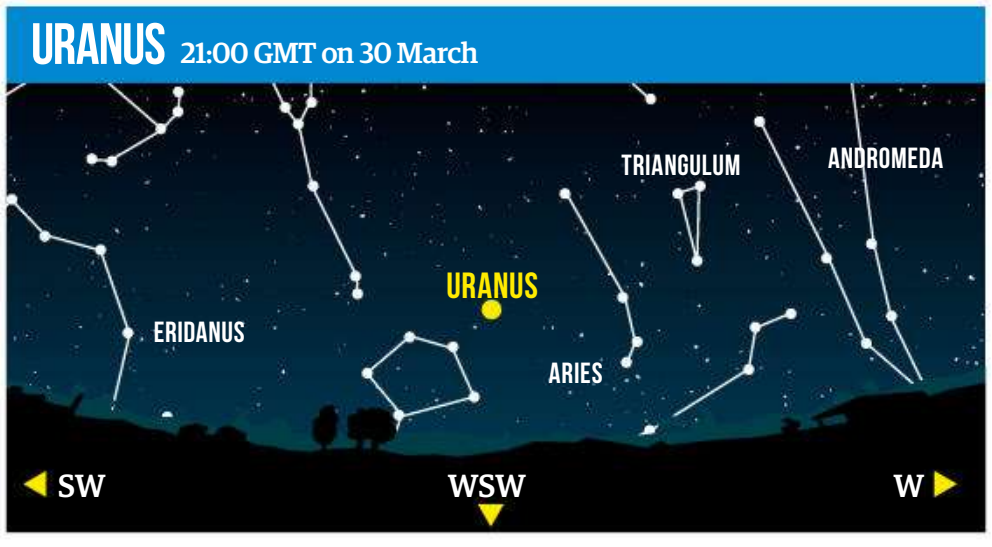
Constellation: Aquarius **Magnitude:** -2.0 **AM/PM:** PM

This will not be a good month for you if you're wanting to see Jupiter. Through last autumn and winter Jupiter dominated the evening sky, forming a pair with Saturn, but that show is now over. At the start of our observing period Jupiter will be very low in the west after sunset, and even shining at magnitude -2.0, it might be hard to spot in the golden twilight.



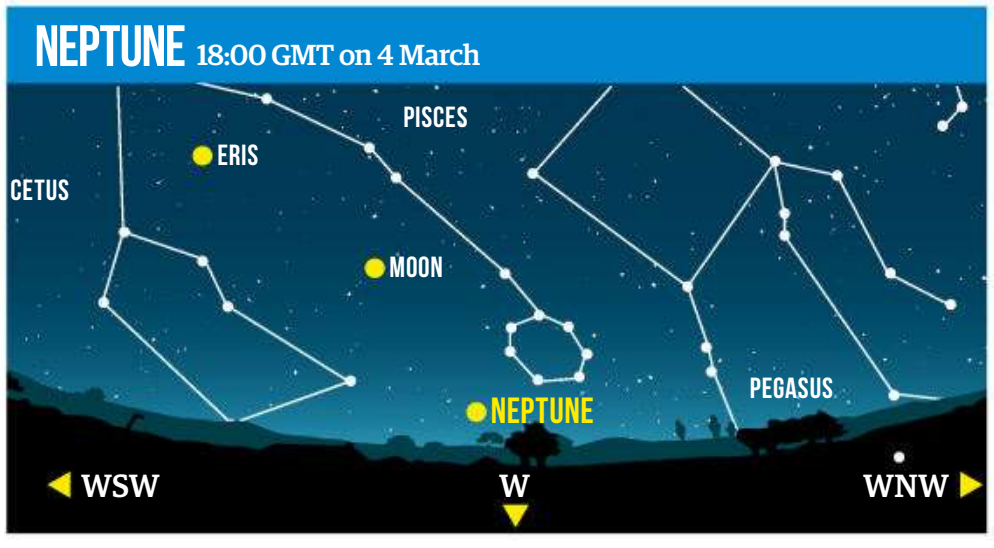
Constellation: Capricornus **Magnitude:** +0.7 **AM/PM:** AM

Saturn will be visible in the morning sky this month, shining to the lower left of brighter Venus. But at only +0.7 the ringed planet will not stand out in the predawn sky, as it rises not long before the Sun. At the end of February it will rise less than half an hour before the Sun, and by the end of our observing period will still only be rising less than an hour before it.



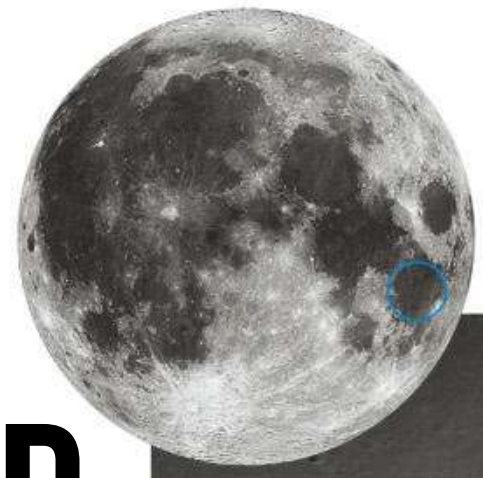
Constellation: Aries **Magnitude:** +5.8 **AM/PM:** PM

Uranus will be visible from sunset through the evening, making it the easiest planet to observe after dark. As the Sun sets Uranus will be halfway up in the southwestern sky. As the hours pass it will slowly arc westwards through the night, setting around midnight at the end of February and 22:00 by the end of March.



Constellation: Aquarius **Magnitude:** +8.0 **AM/PM:** PM

At the end of February Neptune will be an evening object, visible after sunset to the upper left of Jupiter. At +8.0 it won't be visible to the naked eye, and will be challenging to see in binoculars and telescopes before it sets around an hour after the Sun. As the days pass Neptune will become harder and harder to see, until it's lost from our view at the start of March.



MOON TOUR

MESSIER AND MESSIER A

These two small craters are an intriguing sight through a telescope this month

Look at the Moon through a powerful telescope, a simple binocular or even just your naked eye and you can tell it had a violent past. Countless craters spatter its surface, each one a wound blasted out of the crust by the impact of a piece of rock or metal that came barrelling in from deep space. Most are so old that they're now just pits, empty eye sockets staring sightlessly from the Moon. But a few craters are young enough that they are still surrounded by systems of rays, bright lines of debris thrown out across the lunar surface when they were formed.

The largest ray systems – streaking away from the giant 'celebrity' craters such as Copernicus, Kepler and Tycho – are obvious to the naked eye on a clear night when the Moon is full. But here and there, dotted across the Moon, you can find smaller, less famous craters with smaller systems of rays which are just as beautiful as their larger counterparts.

One such crater is Messier A, a hole blasted out of Mare Fecunditatis, the Sea of Fertility, around 1 billion years ago. Lying just south of the equator, Messier A is a mere nine kilometres (5.6 miles) across, meaning you really need a telescope to see it – although it might just be glimpsed through a powerful binocular on a perfect night. It's actually one of a pair of craters, close to the crater Messier, which is more oblong in shape.

© NASA

TOP TIP!

Use a Moon filter when looking at Messier and Messier A, especially when the Moon is full. The features will stand out much more clearly.

However, Messier A is the more striking of the two because a pair of long, narrow debris rays, jut away from it to the west, make it look like a comet. In fact, its comet-like appearance is quite appropriate, because Messier A and its near neighbour were named after the French observer Charles Messier, the 18th-century comet hunter who compiled a catalogue of clusters, galaxies and nebulae in the sky so that he wouldn't mistake them for new comets.

There has always been speculation about how Messier and Messier A were formed. Some observers favour a double-impact scenario, in which a pair of objects hit the Moon simultaneously, creating a pair of craters. Another – and a rather more romantic theory – is that a single body hit the Moon at such a shallow angle that after forming Messier it actually bounced back off the surface of the Moon – like one of the Dambusters' bombs bouncing off a reservoir, or more recently the Philae lander – and came down a second time, blasting Messier A out of the Moon and sending a huge spray of material away from it, forming the long, bright rays we see today. This actually makes sense: look at Messier through a telescope and it's strikingly elongated, which is what you would expect a crater caused by a low-angle grazing impact to look like.

So when can you see these intriguing craters this month? As this issue of **All About Space** hits the shelves and drops through letter boxes, the Moon is a waning crescent, low in the southeast after sunset. Messier and Messier A will not become visible until 7 March, when the terminator sweeps over central Mare Fecunditatis, bathing the Messier pair in sunlight. The craters remain visible until 21 March, when the terminator rolls back over them, plunging them into darkness once more. By then the Moon will be at its waning gibbous phase in the morning sky, not too far from dwarf planet Haumea.

Between those two dates the pair will be easy to see through even a small telescope, with Messier A's rays at their most obvious through early March. When magnified through a larger telescope you'll easily be able to see the gap between Messier A's twin rays. It should remind you of a classic comet tail, airbrushed onto the Moon's grey-white surface.

NAKED EYE & BINOCULAR TARGETS

Take a tour of Leo, Cancer and Gemini this evening, without the need for a telescope

GEMINI

1 Castor & Pollux (Alpha Geminorum & Beta Geminorum)
These two bright stars mark the heads of Gemini (the Twins). Pollux, a giant star with an orange hue, is the brighter of the two stars, with a magnitude of +1.14. Castor, which glows at a magnitude of +1.57 and has a blue-white colour, is a multiple star system – you'll need at least a small telescope to resolve these stars though. Castor and Pollux are visible in the same field of view with a pair of 10x50 binoculars.

LYNX

2 Beehive Cluster (Messier 44)
Looking like a fuzzy patch of light to the naked eye, binoculars with a magnification of at least 10x50 show this lovely star cluster in all its glory. Also known as Praesepe, Messier 44 fits well in the field of view of a pair of binoculars and contains red giants, white dwarfs and stars similar to our Sun. Its bright blue-white members are the most obvious when viewed by the unaided eye.

3 The Sickle
This asterism, looking like a backwards question mark, is the head and mane of Leo the Lion and is a sign that spring is here. The Sickle contains the blue-white star Regulus, orange Algeiba and yellow Adhafera.

CANCER

4 Messier 67
One of the oldest known open clusters, Messier 67 contains more than 100 stars that are similar to the Sun, along with numerous red giants. Messier 67 is nicknamed the King Cobra Cluster and appears the same size as the full Moon. Through a small pair of binoculars, you should be able to see an elongated patch of light.

HYDRA

LEO

5 Regulus (Alpha Leonis)
The brightest star in Leo, Regulus is 78 light years away and is a multiple star system. Regulus marks the bottom of The Sickle. Regulus is one of the brightest stars in the sky, shining with a white-blue hue at a magnitude of +1.4.

NGC 2903

DEEP SKY CHALLENGE

THE LION'S GALAXIES

The evenings of early spring are welcomed by the arrival of some lovely deep-sky objects

Spring is known as the season of the galaxies to astronomers, as the nightside of Earth is facing away from the Milky Way and out into deep space, which is littered with other such 'island universes' as our own. The distances to these objects are truly vast, and so we often see them as small, hazy patches of light, but these objects are anything but small.

Like the Milky Way, they contain billions of stars, clusters and nebulae. They also come in various shapes and sizes and can be a little smaller or even a lot larger than our home galaxy. Due to line-of-sight effects, as well as gravitational ones, they can also seem to occur in groups, such as the Leo Triplet, or they might just appear as isolated misty patches of light, floating in the depths of space.

Messier 95

Source: Wikipedia Commons © Ngc1535

Source: Wikipedia Commons © Jschulman555

"THE DISTANCES TO THESE ARE TRULY VAST, AND SO WE SEE THEM AS SMALL, HAZY PATCHES OF LIGHT"

1 NGC 2903

The spiral galaxy NGC 2903 is considered to be 'active' due to the high rate of star birth going on in its core. Observations using modest telescope apertures reveal a bright oval embedded in a haze. Good sky conditions will reveal its spiral arms.

2 Messier 95

Look through a telescope at Messier 95 and you'll see that it's a face-on spiral galaxy. Located 38 million light years away in the Lion's belly, Messier 95 is home to a supernova which was discovered in 2012.

3 Messier 96

This galaxy has a spiral structure and can be found in the 'stomach' of Leo. It's said that Messier 96 is of a similar size to the Milky Way, at 100,000 light years across. Small telescopes reveal a very faint patch of light – the galaxy's oval core.

4 Messier 105

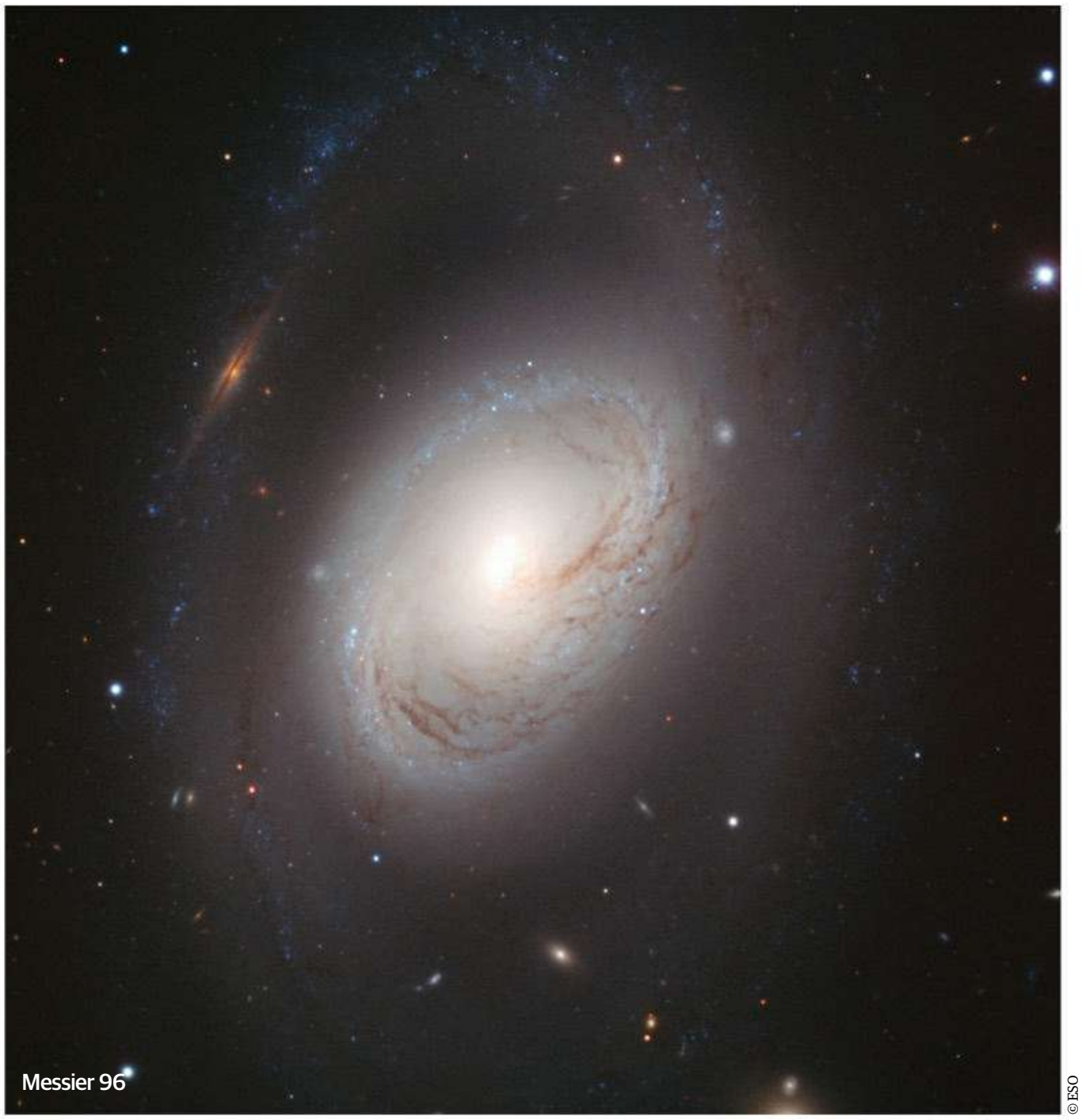
Being an elliptical galaxy, Messier 105 doesn't have a great deal of detail, with even the largest telescopes showing it as a blob of light. Telescopes with apertures of at least ten inches will reveal neighbouring NGC 3384 and NGC 3389 in the same field of view.

5 NGC 3489

Large-aperture telescopes will reveal NGC 3489's bright and fuzzy core. This lenticular galaxy is 32 million light years away, and with a magnitude of +10.3 it's best viewed under very good observing conditions.

6 The Leo Triplet

Made up of Messier 65, Messier 66 and NGC 3628, this famous group is a popular target for those with not just a telescope, but who like to dabble in astrophotography. These three large spiral galaxies can be viewed in the same field of view.



Messier 96

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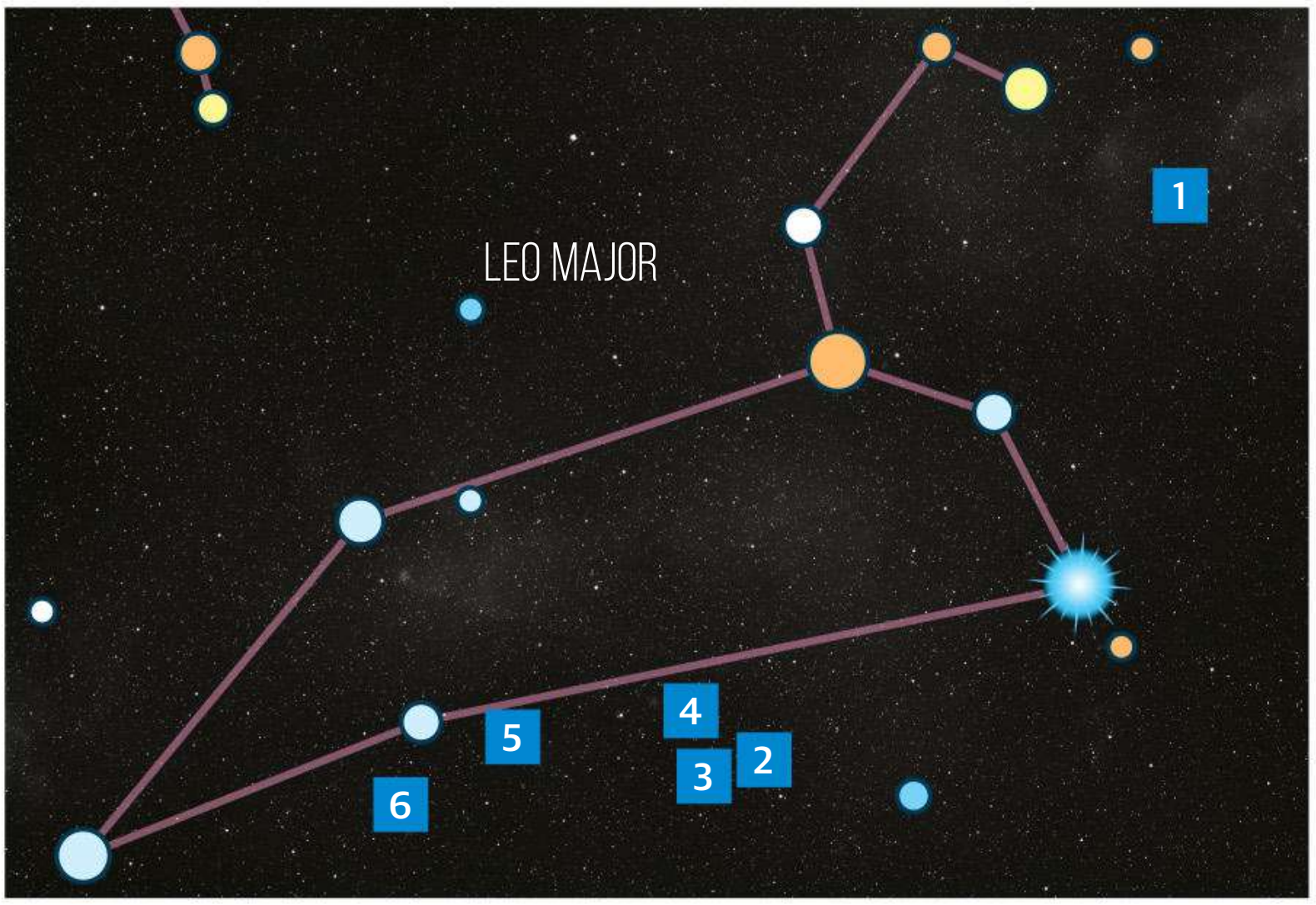


THE NORTHERN HEMISPHERE

The spring constellations are teeming with galaxies for deep-sky enthusiasts

Now March has come, observers are able to enjoy spring's galaxies, many of which are circumpolar, through the evening. While you'll have to be quick to observe the galaxies of Andromeda as they start to head towards the horizon, those found in Virgo and Ursa Major are ideal for those with at least a small telescope. Globular cluster fans are in for a treat this month as the Great Globular Cluster in Hercules (Messier 13), which shines at magnitude +5.9, and its +6.5 magnitude neighbour Messier 92 will not set until around 05:00. If you prefer using binoculars, there are a variety of targets to be observed, such as the bright star system Capella in Auriga, as well as double stars Mizar and Alcor in the handle of the Big Dipper.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

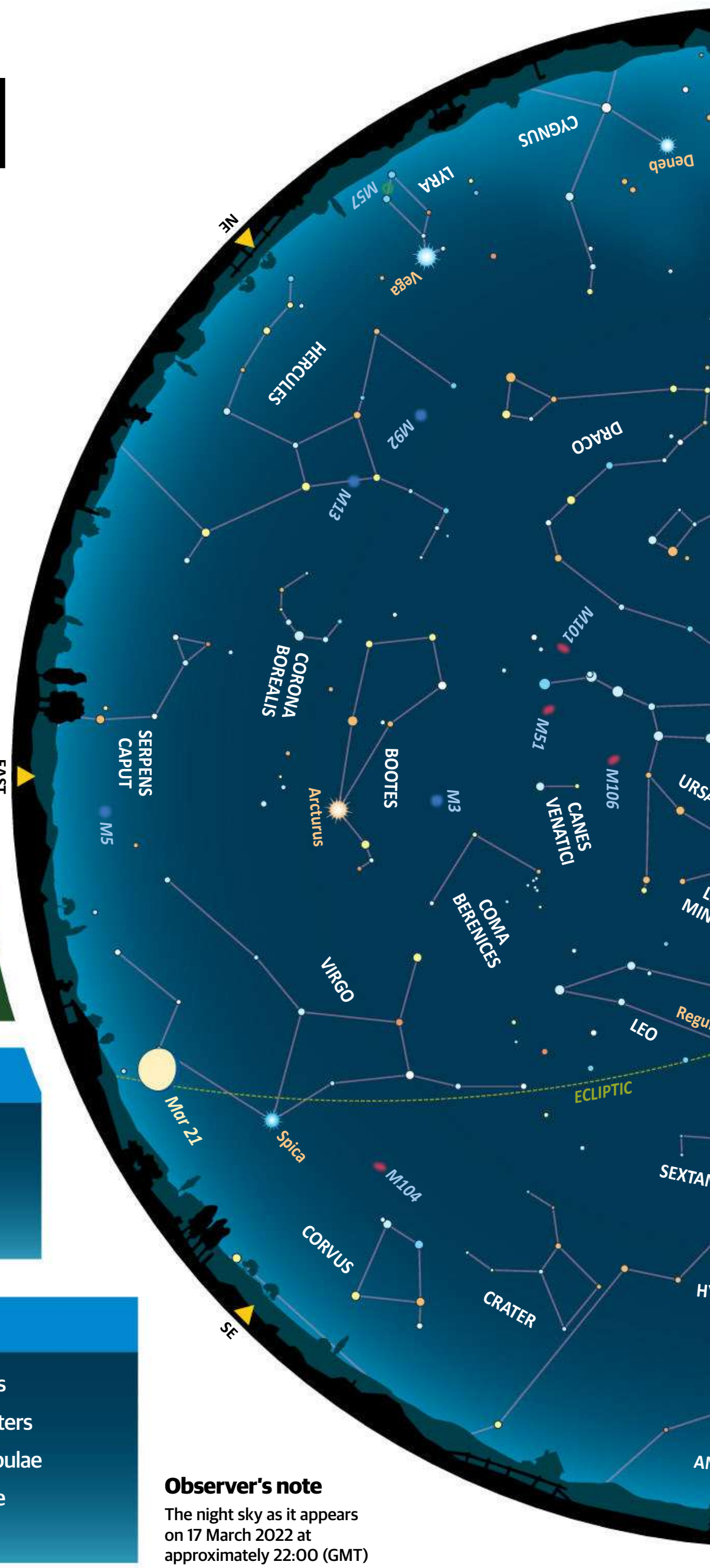
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- A
- F
- G
- K
- M

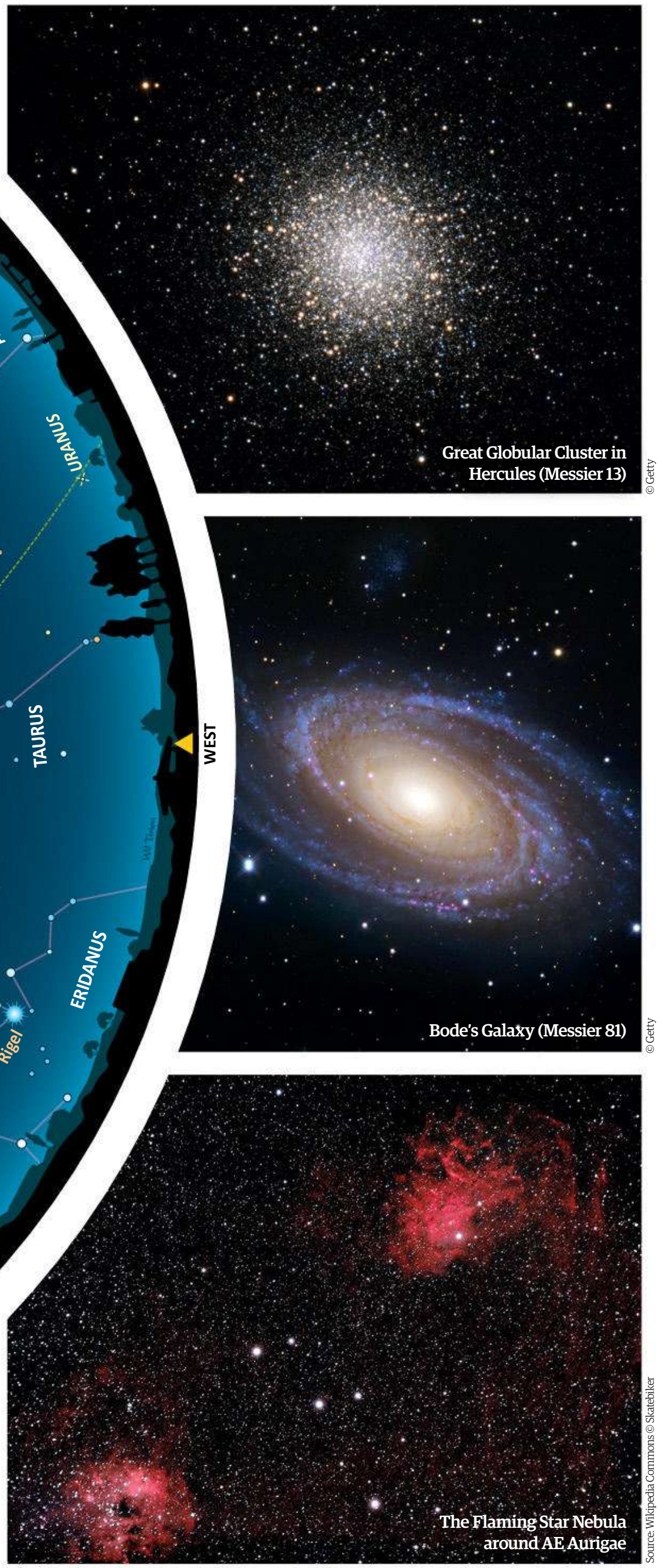
DEEP-SKY OBJECTS

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note

The night sky as it appears on 17 March 2022 at approximately 22:00 (GMT)



Great Globular Cluster in Hercules (Messier 13)

© Getty

Bode's Galaxy (Messier 81)

© Getty

The Flaming Star Nebula around AE Aurigae

Source: Wikipedia Commons © Skatebiker

STARGAZER

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

Phil Howarth

Location: Dorset, UK

"I've had an explosion of creativity and passion with capturing fragments of the night sky above us. With the spectacular Perseid meteor shower and perfect conditions for observing the night sky, I've been up late most nights to take in the views. Combining my interests in photography and astronomy has been a steep learning curve, but experiencing the silence, solitude and breathtaking views has sparked a new chapter in my photographic journey."

Above: Durdle Door, Dorset

Peter Louer

Location: Teide National Park, Tenerife

"I moved to Tenerife from the UK when I retired in 2013, which allowed me to concentrate on my passion for astronomy and astrophotography. The combination of altitude and dry atmosphere gives great seeing, even though I have street lights directly outside my house. If I want even better seeing I'm only an hour away from Teide National Park, which is 2,200 metres (7,220 feet) above sea level."

Left: The California Nebula (NGC 1499)

Right: The Pleiades (Messier 45)

Below: Andromeda Galaxy (Messier 31)

Soumyadeep Mukherjee

Location: Kolkata, India

"This image presents a comparison between a black-and-white and a colourful Moon. The Moon, as we see it with our naked eye, appears to be in greyscale like the one on the right side. However, the Moon's surface is rich in minerals which have their own colours. Some are subtle, but they can be enhanced, as in the one on the left side, also known as the mineral Moon. Note that the colours are not added, but are enhanced to show the different mineral compositions on the lunar surface. The Moon presented here is the first full Moon of 2022, also known as the Wolf Moon. This shot is a stack of 350 images."

Right: The January Wolf Moon

REVIEW

COSMIC WATCH

A visually stunning and interactive app that allows users to experience Earth, the Solar System and clocks that expand your knowledge of the universe

Reviewed by Lauren Allain

STARGAZING APP ADVICE

Cost: £4.89 / $4.49 (Google Play)
£5.99 / $6.99 (Apple)
Version: 2.0

BEST FOR...

- SMALL BUDGETS
- BEGINNER
- STARS & CONSTELLATIONS
- PLANETS
- MOON PHASES
- FAMILIES

Cosmic Watch conjures up ideas of observing the cosmos in the night sky, but even at first glance it's apparent that Cosmic Watch is so much more. Labelled as the world's first 3D astronomical clock, the Cosmic Watch app is a bit of a choose-your-own-adventure story, offering you the chance to view the planets in multiple ways. Built by Celestial Dynamics Ltd in Zurich, Switzerland, Cosmic Watch launched in the spring of 2015, and the most recent update came in 2018.

The app reviews well with users, earning 4.5 stars from Android and iOS reviews, closing ranks with many of the best stargazing apps. Even visiting the download landing page for Cosmic Watch lets users know they're in for an impressive experience, giving users a taste of the stunning visualisations provided in the app.

The software includes three main modes: astronomy, astrology and world clock. Each offers an in-depth and high-quality view with plenty of customisation options. We found that one of the most appealing features was putting the app on a hyperspeed setting and relaxing while watching the universe move throughout time. While the majority of stargazing apps plant users on Earth's surface to view the sky, Cosmic Watch offers the ability to observe from many different points of view and has dozens of optional layers.

Setting up is simple, with the app initially asking users to set their preferred location from a database of 23,000 cities, after which it takes users to the default view of clock mode. From here users can click all over the world to get real-time data and views. Focusing on the world clock modes, the app is capable of showing day or night, as well as indicating seasons, an equatorial clock face and an ecliptic clock.

Astronomy settings include showing planets, constellations, stars and the zodiac. It's also possible to turn on long-exposure, interstellar gas and dust and sky gradient. Further settings allow you to see horizontal coordinates, celestial rings and planetary orbits. Users can also toggle between a heliocentric or geocentric view at any time. You can set the app to send notifications, too, so you'll be reminded of certain celestial events and lunar phases.

But that doesn't mean that you can't use it as a handy star map, as that feature is packed in along with all of the above. As with popular apps like Star Walk 2 and Stellarium, you just have to navigate to the right section on the app and then point your phone at the sky.

Even getting used to the app's functions is a joy, allowing you to explore exactly what views Cosmic Watch offers and what overlays are possible with each view. A control panel running down the left side of the screen allows users to focus on the world clock, astronomy or astrology aspects of the app. The bottom-right corner offers time controls, and the upper-right menu creates a clean screen by removing all setting icons. Toggling the many options on and off might be overwhelming at first, and occasionally changing an option in one tab opens and closes options in another tab.

Overall, the app hosts an incredible amount of customisations to view both Earth and the Solar System, but it will take some time to understand and learn how to utilise all of the options. It's undeniably a little fiddly, and is arguably

Left: Clocks can be fully customised

"COSMIC WATCH OFFERS THE ABILITY TO OBSERVE FROM MANY DIFFERENT POINTS OF VIEW"

better suited to larger tablet screens rather than smartphones. However, it's well worth the time to explore just how powerful and educational Cosmic Watch can be.

Users hoping to get the most out of Cosmic Watch should dive into the comprehensive online user guide to get a firm grasp on every feature. The online guide also points out that Cosmic Watch could be used as a desktop clock when installed and displayed on a tablet. Some users could find this to be an aesthetically appealing clock since it can be highly customised to view Earth or the Solar System. Another worthwhile feature of Cosmic Watch is the app's screenshot option. Indicated as a red dot on the right side, the app can take, share and save screenshots of your favourite views easily.

Cosmic Watch costs £4.89 or $4.49 on Android devices through Google Play and £5.99 or $6.99 for Apple devices through the App Store. While there are many great stargazing apps offered for free, none offer the comprehensive views and information that Cosmic Watch offers. The app comes with no ads, which is extremely useful in this case since the app is already slightly cluttered with icons along the left side and the timing indicator on the right.

FOR

- ⊕ Incredibly advanced and detailed features
- ⊕ Endless customisation of views
- ⊕ Stunning visualisations of Earth and the Solar System
- ⊕ Powerful timelapse function both forward and back

AGAINST

- ⊖ Free apps could be a better starting point
- ⊖ Help function reverts to the online manual
- ⊖ Not suited to small screens

The design of the icons is not a negative, but it does take some time to learn what each option controls. Anyone interested in our Solar System, clocks or calendars will likely find the price of Cosmic Watch to be money well spent. The app has countless combinations of viewing options to keep users happily observing the world we live in. At times the app's stunning visualisations can feel almost meditative, serving as an immersive break from any stressors.

Educators or young learners could also find the app to be well worthwhile, giving an interactive opportunity to explore seasons, clocks, planets, the Solar System and Earth from viewpoints all over the universe.

Above: Cosmic Watch can be utilised as a star map

Below: Users can switch to a heliocentric view of the Solar System at any time

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ALL ABOUT SPACE BOOK OF MARS

The history of Mars is intrinsically bound up with that of Earth – some scientists even think that the original building blocks of life came from the Red Planet. The European Space Agency's Mars Express probe, undeterred by the failure of its Beagle 2 lander back in 2003, recently beamed back some of the clearest images yet of a crater filled with water ice in the northern lowlands of what was once thought to be an arid world. Despite a chequered history of failed spacecraft and the so-called 'Mars curse', the Red Planet is finally giving up some of its secrets. In this book it's revealed what scientists know so far about the planet and the theories that may help us to understand it further, exploring how one day we could make it into another human home.

EVERYTHING YOU NEED TO KNOW ABOUT MARS

Is there life on Mars, or was there in the distant past? Could there be in the future in the shape of humans? Discover the answers to all of these questions and more in this guide to everything you need to know about Mars. Find out about its geology, its ancient history and its structure. Marvel at its record-breaking landscape, featuring some of the largest geographical features in the Solar System. Explore its surface, its moons and the reasons why it wobbles on its axis and is losing its sky. Learn about the probes, robots and rovers we've sent to explore it, and why landing a craft on Mars successfully is such a challenge. Meet some of the scientists and would-be Mars explorers who are looking at the challenges Mars presents, and how they can be overcome, in the hope of one day setting foot on the Red Planet.

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IN THE SHOPS

The latest books, apps, software, tech and accessories for space and astronomy fans alike

1

2

3

FOR DECORATION

GEMSTONE SOLAR SYSTEM

Cost: £40.99 / $41.96

From: Amazon

1 Spruce up your workstation with this gemstone Solar System, including dwarf planet Pluto. Each celestial body is made from a different gemstone, with their unique colours representing the different bodies in our Solar System. The set includes Mercury (labradorite), Venus (woodgrain stone), Earth (sodalite), Mars (obsidian), Jupiter (tiger's eye), Saturn (yellow onyx), Uranus and Neptune (aventurine) and dwarf planet Pluto (strawberry stone). The ideal gift for budding astronomers, gem collectors and space enthusiasts.

FOR YOUR HOME

STAR TEALIGHT SET

Cost: £3.50 (approx. $4.75)

From: Nordic House

2 Set the mood with this set of six adorable star tealights from Nordic House. Each candle sits in its little clear holder to show off the delicate star design. The candles are made from paraffin wax and measure 5.5 centimetres (2.2 inches) wide and 2.5 centimetres (one inch) high. Sold as a set of six, these candles are the perfect home accessory to create a celestial display that will twinkle into the night.

FOR ASTROPHOTOGRAPHERS

ROKINON 14MM F/2.8 LENS

Cost: £279.87 / $299

From: Amazon

3 This lens is about as wide as you can go on one of the best cameras for astrophotography without fisheye distortion, dropping your aperture lower than f/2.8 or spending a lot more money, making it an enticing lens for astrophotographers with Canon cameras. Taking in vast swathes of the night sky with its 115-degree field of view, a 14mm lens can be used for getting up close to things, capturing the inside of rooms or fitting the majesty of entire mountains in the frame. It's a specialist focal length, but appeals to enough niches that having one in your lens collection isn't a complete extravagance.

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6

"BATHE IN THE WARM GLOW OF A ROARING FIRE AND ENJOY THE WHIMSICAL STAR AND MOON ACCENTS"

FOR WRITING

MIDNIGHT ASTRAL ROLLERBALL PEN

Cost: £45.80 (approx. $62.05)

From: Parker

4 This pen by Parker makes for an impressive space-inspired gift. Hold the cosmos in your hands and see where your writing journey will take you with this ball pen adorned with a map of the constellations. The stainless-steel ball pen is coated in a blue varnish and topped with a cap and clip decorated with the Parker arrow. You can choose from a wide range of gift boxes, including leather and wood, for a professional finish. If you're looking for that special personal touch, you can also add an engraving for £4.60 ($6.20).

FOR YOUR PATIO

STAR AND MOON STEEL WOOD-BURNING FIRE PIT

Cost: £109.99 (approx. $149)

From: Wayfair

5 Looking for something to warm you up on a chilly evening? This wood-burning fire pit may be just what you're looking for. Bathe in the warm glow of a roaring fire and enjoy the whimsical star and moon accents that set this fire pit apart. The steel legs and sturdy design ensure this celestial fire pit will be the focal point of your outdoor space for many years. It includes a log grate, spark screen, fire poker and cover. This would make for a great addition to your outdoor space or an ideal present for the space lover in your life.

FOR OBSERVERS

PETZL ACTIK CORE 450 LUMEN HEADTORCH

Cost: £59.95 (approx. $81.25)

From: Petzl

6 The rechargeable Petzl headtorch includes a handy red-light feature to preserve night vision, making it the perfect accessory for astronomers. It also offers an impressive 450 lumens of power along with a multi-beam design, so can be used during outdoor activities such as mountaineering, running and hiking. The reflective headband also helps to provide good night visibility. As well as being rechargeable, this practical headtorch is also compatible with three AAA/LR03 batteries due to the pragmatic hybrid concept design.

NICOLAUS COPERNICUS

The astronomer changed our view of the universe forever

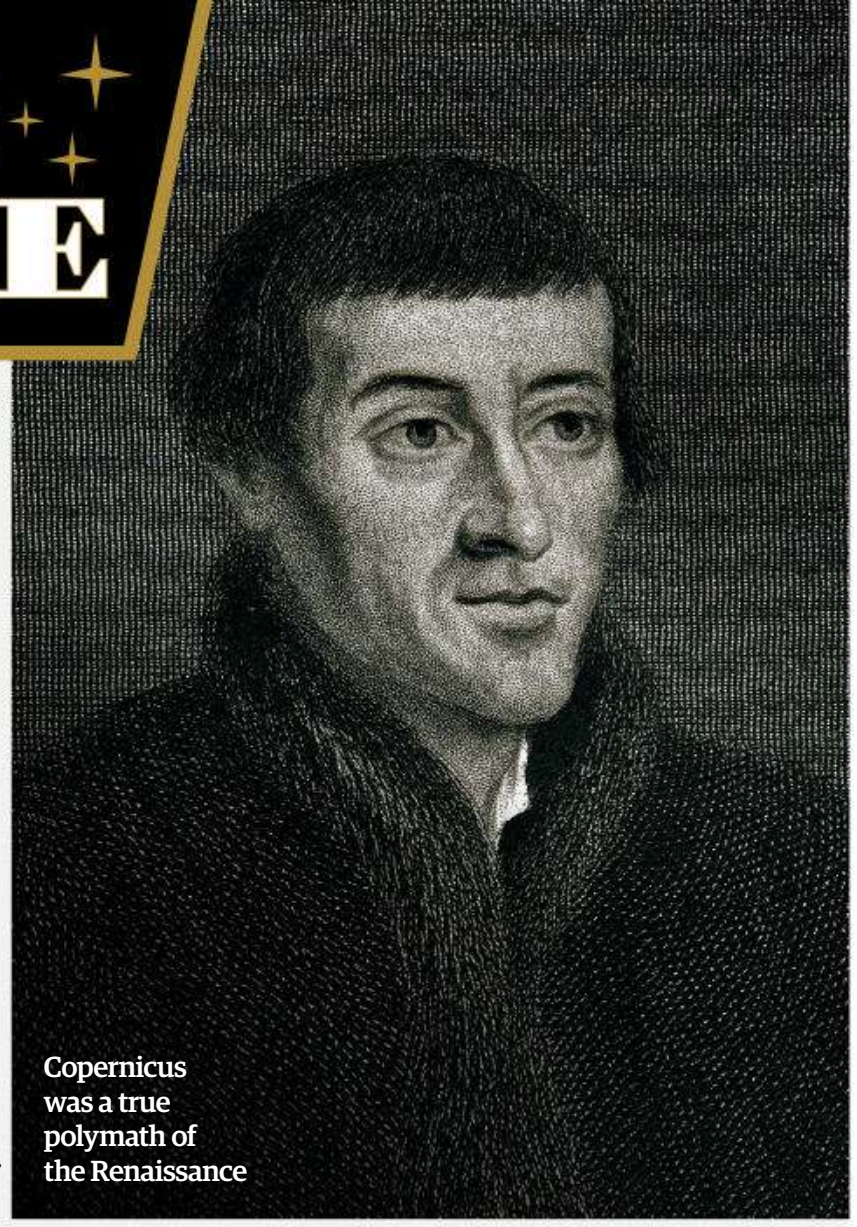
Copernicus proposed his theory that the planets revolved around the Sun in the 1500s when most people believed that Earth was the centre of the universe. Although his model wasn't completely correct, it formed a strong foundation for future scientists. Indeed, other astronomers built on Copernicus' work, proving that our planet is just one world orbiting one star in a vast cosmos loaded with both, and that we're far from the centre of anything.

Born on 19 February 1473 in Toruń, Poland, Mikołaj Kopernik - Copernicus is the Latinised form of his name - received an excellent education. Copernicus' father passed away when Copernicus was young, and his uncle became a leading figure in his life, guiding his studies. Copernicus' uncle wanted him to study the laws and regulations of the Catholic Church and then return home to become a canon - a type of official in the Catholic Church. However, while visiting several academic institutions, Copernicus spent most of his time studying mathematics and astronomy. While attending the University of Bologna, Copernicus lived and worked with astronomy professor Domenico Maria de Novara, doing research and helping him make observations of the heavens.

Due to his uncle's influence, Copernicus did become a canon in Warmia in northern Poland, although he never took orders as a priest. He conducted his astronomical research in between his duties as canon.

In 1514, Copernicus distributed a handwritten book to his friends that set out his view of the universe. In it, he proposed that the centre of the universe was not Earth, but that the Sun lay near it. He also suggested that Earth's rotation accounted for the rising and setting of the Sun, the movement of the stars and that the cycle of seasons was caused by Earth's revolutions around the Sun. Finally, he correctly proposed that Earth's motion through space caused the retrograde motion of the planets across the night sky - planets sometimes move in the same direction as stars, slowly across the sky from night to night, but sometimes they move in the opposite, or retrograde direction.

Copernicus finished the first manuscript of his book, *De revolutionibus orbium coelestium*



Copernicus was a true polymath of the Renaissance

© Getty

(*On the Revolutions of the Heavenly Spheres*), in 1532. In it, Copernicus established that the planets orbited the Sun rather than Earth. He also laid out his model of the Solar System and the path of the planets. However, he didn't publish the book until 1543, just two months before he died. Copernicus passed away on 24 May 1543 of a stroke. He was 70.

In 2008, researchers announced that a skull found in Frombork Cathedral did indeed belong to the astronomer. By matching DNA from the skull to hairs found in books once owned by Copernicus, the scientists confirmed the identity of the astronomer.

In 2010, his remains were blessed with holy water by some of Poland's highest ranking clerics before being reburied, his grave marked with a black granite tombstone decorated with a model of the Solar System. The tomb marks both his scientific contributions and his service as a Catholic Church canon.

"Today's funeral has symbolic value in that it is a gesture of reconciliation between science and faith," Jacek Jezierski, a local bishop who encouraged the search for Copernicus' remains, said at the reburial. "Science and faith can be reconciled." His original unmarked grave was not linked to suspicions of heresy, however, as his ideas were only just being discussed and had yet to be forcefully condemned, according to Jack Repcheck, author of *Copernicus' Secret: How the Scientific Revolution Began*. "Why was he just buried along with everyone else, like every other canon in Frombork?" Repcheck posed. "Because at the time of his death he was just any other canon in Frombork. He was not the iconic hero that he has become."

All About Space

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Content Director **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Staff Writer **Daisy Dobrijevic**
Production Editor **Nikole Robinson**
Senior Art Editor **Duncan Crook**
Photography **Olly Curtis**

Contributors
Lauren Allain, Stuart Atkinson, Meghan Bartels, Mathew Browne, Charles Q. Choi, David Crookes, Chelsea Gohd, Ashley Hamer, Elizabeth Howell, Robert Lea, Samantha Mathewson, Stephanie Pappas, Tereza Pultarova, Giles Sparrow, Brandon Specktor, Colin Stuart, Ben Turner

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Tobias Roetsch ; Getty

Photography
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Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Advertising Manager **Matthew Johnson**
matthew.johnston@futurenet.com
07974 408 083
Account Manager **Garry Brookes**
garry.brookes@futurenet.com
0330 390 6637

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Chief Growth Officer **Claire MacLellan**
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